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# INJURIES PRODUCED BY CONTACT WITH ELECTRIC CIRCUITS.*

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ABSTRACT.

This paper discusses the results of a series of experimental investigations that have been conducted at The Johns Hopkins University on the effects of electric shock. Rats and dogs were used as the experimental animals. They were completely anesthetized before the experiments. Studies of the effects produced by electric current upon the nervous system and upon the heart are reported. Three types of circuits were used in the work, namely, direct current, alternating current, and the discharge of an impulse generator.

In the first series of experiments, the effect of voltage was studied and it was found that low voltage alternating current circuits are much more deadly than direct current circuits of the same voltage. At voltages of 1,000 and higher the reverse is the case. In this work, the importance of the size of the animal as related to the injury was definitely established, larger animals being able to withstand a greater current than those small in size.

The resistance offered by a body in an electrical circuit was determined. The resistance is made up of two parts—the contact resistance, and the ohmic resistance of the body proper. The resistances offered at the contacts are of the nature of a voltage drop and are largely independent of the current flowing. The importance of contact resistances in industrial accidents is emphasized.

In a second series of experiments the effect of the current path through the

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body was investigated and it was found that there was little or no evidence of damage to organs lying outside of the main current pathway.

The experiments with the impulse generator also involved various current pathways through the body and checked the results found with the direct and alternating current circuits. As a result of the experiments with the impulse generator it was clearly demonstrated that damage to the nervous system may be produced by electricity. The same type of nerve cell injury was found in the brains of animals that has been reported in the case of men subjected to electric shock.

In the study of the effect of electricity upon the heart, the current actually flowing through that organ for different current pathways was measured. It was found that slightly less than one-tenth of the total current flowing parallel to the long axis of the body passes through the heart. With the current flowing transversely through the body, approximately three per cent. passes through the heart.

The paper also discusses a number of phenomena that have been reported in the case of human accidents on electrical circuits such as the loss of consciousness, damage to the nervous system, hemorrhages, convulsions, emission and ventricular fibrillation. Similar effects were observed in the experiments upon animals.

Accidents due to contact with electric circuits have become progressively more frequent with the increasing use of electricity in industry and the home. At present the death rate in the United States is 1.0 per 100,000 inhabitants. Roughly, fifty per cent. of the accidents are fatal.

This paper deals with the results of a number of experimental investigations conducted at The Johns Hopkins University on the effects of electric shocks. Funds for the support of this work were made available through the generosity of the Committee on Physiology of the Conference on Electric Shock.

## GENERAL FACTORS IN ACCIDENTS.

The number of accidents caused by electric shock is increasing and this is particularly true of those due to contact with low voltage circuits. Maclachlan [1] in 1930 published an excellent summary of 479 cases of electric shock for which complete data were available. He showed that men are more commonly injured than women and that the ages of greatest incidence of shock lie between fifteen and thirty, perhaps owing to the greater carelessness of youth. Accidents are more common in the summer months, due to the smaller protection offered by the clothing and to the presence of

perspiration, which decreases the skin resistance. Maclachlan found that accidents are most common at the end of the working day when fatigue is at a maximum. The current path through the body is usually from the right hand to the feet.

### EXPERIMENTAL STUDIES.

The injuries produced by electric currents have been studied in two ways: circumstances relating to human accidents have been carefully recorded and tabulated, and the effects of shocks upon animals have been studied. Animals differ widely in their ability to withstand electric shocks and it is difficult to apply experimental results thus obtained directly to man. Dogs are killed by relatively small currents, while rats are much more resistant. The difference lies to a great extent in the behavior of the heart. The adult dog's heart is readily thrown into ventricular fibrillation by a small electric current, and does not recover from this condition spontaneously. On the other hand, the ventricles of the rat's heart apparently do not fibrillate. When these different reactions of animals are kept in mind, the variabilities are an aid rather than a hindrance to experimental work, provided the proper animal is selected. Thus, the authors have used the rat in their study of the changes in the nervous system, and the dog in their study of ventricular fibrillation. By ventricular fibrillation is meant the failure of the ventricles of the heart to beat with a coördinated rhythm; instead all the individual muscle fibers contract asynchronously. It must be emphasized that all of the animals were thoroughly anesthetized throughout the entire experimental procedure.

### TYPES OF CIRCUITS USED.

In the experimental studies of electric shock discussed in this paper three types of circuits have been employed, namely, continuous or direct current, alternating 60-cycle current, and the discharge of an impulse or surge generator. Accidents in industry and the home take place on constant voltage systems and the current value is seldom, if ever, accurately known. Therefore, the authors, although realizing the importance of the intensity of the current, have used circuits of constant voltage; noting, however, the amount of current flowing.

EFFECT OF VOLTAGE.

The relative damage produced by continuous and alternating circuits of 110, 220, 500 and 1,000 volts has been tested, using a large number of rats.[2, 3] Since electricity does not produce ventricular fibrillation in the rat, these experiments record the damage produced in the nervous system.

In this series, one of the electrodes was attached to the top of the head and the other was fastened to the base of the tail. Before attaching the electrodes, the skin and hair were moistened with a saturated salt solution. The circuit was held closed for varying lengths of time and at each voltage the first shocks were of short duration, being gradually increased until it was no longer possible to resuscitate the animals.

The results of these tests are summarized in Table I. A considerable number of animals were paralyzed, principally by the alternating circuit. These animals had no chance of permanent recovery and could be kept alive only a few days. Many of the paralyzed rats became incontinent, showed blood in the urine and hemorrhage in the spinal cord. When these paralyzed animals are taken into account it is clearly evident that at 110, 220 and also at 500 volts, the alternating circuit is much more deadly to rats than the continuous circuits of the corresponding voltages. The direct current 1,000-volt circuit was found to be much more deadly than

TABLE I.

*Effect of Voltage.*

| Voltage. | Number Tested. | Duration of Shock Sec. | Current Milliamp. | Per Cent. Receiving Artificial Respiration. | Per Cent. Paralyzed. | Per Cent. Died. | Per Cent. Immediate Recovery. | Average Resistance Ohms. |
|---|---|---|---|---|---|---|---|---|
| A.C.—110 | 11 | 10–30 | 25–48 | 90 | 9 | 27 | 64 | 3,091 |
| D.C.—110 | 33 | 5–60 | 28–47 | 30 | 3 | 12 | 85 | 2,685 |
| A.C.—220 | 28 | 5–14 | 80–200 | 93 | 38 | 34 | 28 | 1,890 |
| D.C.—220 | 19 | 5–30 | 100–200 | 74 | 5 | 42 | 53 | 1,635 |
| A.C.—500 | 26 | 1–4 | 240–490 | 73 | 50 | 12 | 38 | 1,425 |
| D.C.—500 | 37 | 1–4 | 280–640 | 89 | 5 | 46 | 49 | 1,385 |
| A.C.—1,000 | 28 | 1–4 | 650–1,200 | 85 | 39 | 32 | 29 | 1,140 |
| D.C.—1,000 | 31 | 1/10–1 | 600–1,100 | 97 | 13 | 58 | 29 | 1,365 |

the corresponding alternating circuit. No rat survived a contact of more than .6 of a second with the continuous circuit while in the alternating group a number of animals were successfully resuscitated following a three second shock.

The striated musculature of the body exhibited a strong tetanic contraction with the alternating currents. With the continuous current the contraction was less in magnitude and clonic movements of the muscles continued throughout the shock. As the voltage of the circuit was increased the contraction of the muscles became more severe and persisted for several seconds after the shock.

In the 500-volt group a number of the rats subjected to the direct current circuit had convulsions and showed increased and abnormal response to all stimuli. Priapism was observed in a number of the male rats subjected to the 1,000-volt continuous current circuit. An emission was observed in many of the animals subjected to the alternating current circuit.

Bleeding from either the eyes or nose or both was a common result of contact with the alternating current circuit but was only observed at the higher voltages in the case of the continuous circuits. At the higher voltages severe injuries occurred at the site of the electrodes with both types of circuits. The burning was more marked after contact with the direct current circuits than the alternating.

Autopsies were performed on all of these rats tested at the different voltages, both continuous and alternating, and the brains and spinal cords were removed and fixed in alcohol. Sections of these were later examined both macroscopically and microscopically for evidence of injuries to the nervous system. The findings are reported in a separate section of this paper.

### RESISTANCE OFFERED BY THE BODY.

When the body forms part of an electric circuit it offers resistance to the passage of the current. This resistance is made up of two parts: one, the contact resistance, and two, the ohmic resistance of the body proper. The contact resistance offered by the calloused palm of a laborer may equal 100,000 ohms per $cm.^2$. In water, however, the resistance may fall to 1,200 to 1,500 ohms per $cm.^2$. The

resistance of the body itself is relatively low, blood being a good conductor. In electrocutions where the contacts are excellent, the total resistance offered by the body is of the order of 200 ohms. In most industrial accidents the resistance offered by the body is an unknown factor. The contacts are usually poor except in bathrooms and other moist places.

In experimental work it is possible to calculate the resistance more accurately and this was done in the series of experiments at varying potentials where one electrode was attached to the head and the other to the base of the tail, both electrodes being covered by cotton moistened with salt solution. An analysis of the data shows that the contact resistance drop is of the form of a voltage drop which is practically independent of the current flowing. The value of the contact voltage drop was calculated on the basis that the current through the animal equaled the applied voltage minus the contact drop divided by the resistance. This gives for rats a voltage drop at each contact of 30 to 35 volts for a total applied voltage of 110 or more volts with this type of electrode. The contact voltage drop is not constant but decreases with the duration of the flow of the current.

Another factor not usually recognized in electrical shock experiments is the relation that exists between the size of the animal and the resistance offered by his body. The authors found that the resistance of the animals decreased gradually with the increase in the weight of the rats. This is clearly shown by Fig. 1 where the resistance in ohms is plotted against the weight in grams for the rats tested at 1,000-volt alternating current. A similar relation existed at the other voltages.

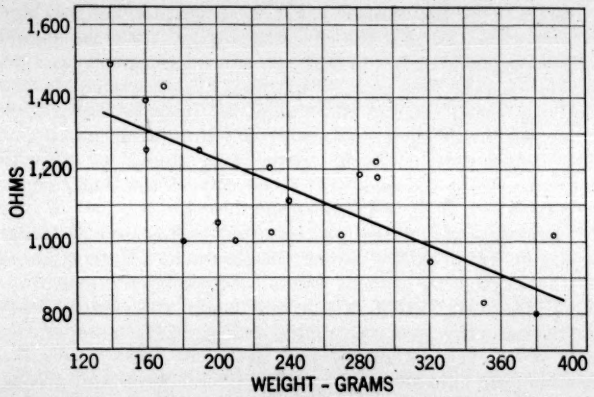
### VOLTAGE OF THE CIRCUIT.

The danger of contact with high voltage circuits is well recognized. However, the opinion still prevails among many engineers and physicians, as well as the public, that the low voltage alternating current circuits used in residences and factories are not dangerous to human beings. *This is not true.* Indeed, the number of accidents on low voltage circuits seems to be increasing more rapidly than those due to contact with high tension. There is on record an authentic case in Italy of a man who was killed by a 46-volt alternating current

circuit. Serious accidents on 110-volt direct current circuits are very rare. In fact, the authors have only been able to learn of one authentic case. In this instance the man was working inside of a boiler in a very confined and cramped space, at a temperature of about 112° F. He had with him a defective portable light supplied from a 120-volt direct current circuit.

The danger of contact with low voltage circuits increases as the contact resistances of the body are lowered. When a person who is well grounded comes into contact with such a

FIG. 1.




Variation of resistance with size of animal for the 1,000-volt A.C. series.

defective electrical device the value of the current may be sufficient to cause death. The majority of such accidents occur in bathrooms, damp cellars, and other places where moist conditions insure lowering of the contact resistances to a negligible value.

When contact is made with a high voltage circuit, the contraction of the muscles is so violent that it often throws the victim clear. On the other hand with low voltages the contraction of the striated musculature is not violent but is well sustained so that it is difficult, if not impossible, for the person to release his hold.

In the experimental studies of the effect on rats of varying voltages it is evident that the injury increases with the increase in voltage and that low voltage alternating current is more dangerous than the corresponding continuous current. The increased injuries and larger death rate found at the higher voltage are probably caused largely by the greater current flowing through the animal.

The current, however, is not the only factor; the voltage of the circuit, aside from the ohms law relation, also determines to some extent the injuries. This was definitely demonstrated by a series of experiments with rats in both 500-volt and 1,000-volt alternating current circuits. Series resistances of the proper value were inserted in the high tension circuit so that the effective voltage across the animal fell to approximately 110 and 220 volts respectively as soon as the current flow was established. Oscillograms showed that the voltage across the animal fell from its initial high value within the first cycle after the closure of the circuit. The resulting injuries and deaths were almost as great as those found in the 500- and 1,000-volt alternating current circuits where the voltage was maintained.

This naturally raised the question as to the effect that would be produced by closing the circuit at different points of the alternating current wave. Accordingly a synchronously operating switch, which would hold the circuit closed for twelve cycles, was constructed and experiments were made with a 60-cycle circuit of 125, 500 and 1,200 rms. volts. A number of animals were tested, half with the circuit closing at the zero of the wave and half with the closure taking place at the maximum point. At 125 volts there was not the slightest difference, at 500 volts a few more animals were killed when the circuit was closed at the peak voltage than at the zero point, and at 1,200 volts the opposite result was found. Therefore, under these conditions the point of the voltage wave at which the circuit is closed has no material effect upon the resultant injury.

### PATHWAY OF CURRENT THROUGH THE BODY.

The location of the points of contact determines to a great extent the path followed by the current in the body and the

resulting electrical injury. In human accidents the path is usually from the hands to the feet. Once inside the body, the current spreads out in a more or less fusiform shape, assuming that the specific resistance of the tissues is uniform. It is difficult to believe, however, that the current density is high in organs lying far outside of the main path. For example, in man, if the contact with the circuit is made with one arm and a leg it is scarcely possible that any appreciable current would pass through the brain. Since the brain appears to be relatively easily injured by electricity one electrode in legal electrocutions is placed upon the head.

A number of experiments were performed with rats to test the relative damage to the organism and particularly to the central nervous system when the current path involved different portions of the body.[4, 5] In this investigation a group of rats were shocked with a 1,000-volt circuit, half with alternating current and half with direct current. In all cases the duration of the contact was two seconds. The position of the electrodes was varied in these experiments. A few tests were made with the electrodes on the head and tail of the animals to check the results of the earlier series. Other current paths investigated were, fore-leg to tail, fore-leg to hind-leg, fore-leg to fore-leg, hind-leg to hind-leg. It is, perhaps, unnecessary to repeat that all of the animals were given ether until they were quite unconscious before the shock was applied.

The results of these experiments are summarized in Table II and show clearly the importance of eliminating the brain from the current path. No rat survived a one second shock at 1,000 volts direct current when the current entered through the head but with the brain eliminated from the circuit 42 per cent. of the animals recovered. It is also interesting to note that in the cases where the current entered by the left fore-leg and passed out at the tail there was a slightly greater percentage of recoveries than when the current entered via the right fore-leg. In the experiments where the current path was from fore-leg to fore-leg no animal survived and this is not to be wondered at when we consider that an average current of 1.24 amperes flowed through the body for two seconds. The chest of these

TABLE II.

*Contact with 1,000-Volt Circuit for Two Seconds.*

| Circuit. | Position of Electrodes | | Number Shocked. | Per Cent. Requiring Artificial Respiration. | Per Cent. Paralyzed. | Per Cent. Immediate Death. | Per Cent. Immediate Recovery. |
|---|---|---|---|---|---|---|---|
| Alternating | Head | Tail | 16 | 88 | 38 | 31 | 31 |
| Continuous | | | 3 | 100 | 0 | 100 | 0 |
| Alternating | Right fore-leg | Tail | 12 | 58 | 25 | 42 | 33 |
| Continuous | | | 12 | 50 | 33 | 25 | 42 |
| Alternating | Left fore-leg | Tail | 12 | 75 | 17 | 25 | 58 |
| Continuous | | | 12 | 58 | 33 | 25 | 42 |
| Alternating | Right fore-leg | Left fore-leg | 4 | 100 | 0 | 100 | 0 |
| Continuous | | | 4 | 100 | 0 | 100 | 0 |
| Alternating | Right hind-leg | Left hind-leg | 7 | 0 | 0 | 14 | 86 |
| Continuous | | | 7 | 29 | 0 | 29 | 71 |
| Alternating | Either fore-leg | Either hind-leg | 12 | 100 | 8 | 59 | 33 |
| Continuous | | | 12 | 100 | 0 | 100 | 0 |

animals was hot to the touch following the shock. Nevertheless for the same current values but with the current path from hind-leg to hind-leg most of the animals recovered and were bright and active within a few minutes after the removal of the electrodes.

Normally one would expect to find little if any difference between the effects produced by a current flowing from either fore-leg to tail or one flowing from either fore-leg to either hind-leg, yet in the latter circuit nearly all of the animals died. The high death rate found here is caused by the low resistance that the animal offers to the flow of the current when its tail is eliminated from the circuit. The average resistance on current paths from fore-legs to hind-legs was less than 70 per cent. of that found from fore-leg to tail.

These experiments demonstrated clearly that the injury to the organism is less severe the less the pathway of the current involves the nervous structures and vital organs. The respiration was interfered with when the current passed through the spinal cord or in the region of the vagus nerve but when the current passed only through the posterior portion of the body the injury was minimal. This series of

experiments was also of particular interest in emphasizing the fact that an animal was not necessarily out of danger when breathing was first started. This same phenomenon is often mentioned in records of human electric shocks. Breathing was started in a number of rats only to cease after a few minutes. A second application of artificial respiration was then necessary and in some cases repeated applications were required to save the animals. Bleeding from the eyes was a common occurrence.

### INJURIES PRODUCED BY SURGE DISCHARGES.[8]

The surge, or impulse, generator is being used more and more in industry and the question has arisen as to the danger to life from shocks received from it. Several experiments were conducted, using a small model impulse generator, the only resistance in the circuit being the body of the animal. Cathode oscillograms taken under these conditions show that the current reached a value of slightly in excess of 100 amperes at 200,000 volts maximum. The wave was very steep, the current reaching its maximum value in one-quarter microsecond, and the entire discharge was completed in about $4\frac{1}{4}$ microseconds.

Seven rats were shocked while lying on the ground plate. Group 1: Table III. A clip was made fast to the desired part of the body. This clip extended several inches above the animal and attracted the spark to a particular location. All of the seven rats breathed spontaneously and were active immediately following the shock. In only two of the animals was there evidence of any abnormality. These two had received the discharge at the level of the shoulders. Their sense of equilibrium was disturbed and they rolled around in small circles for some ten minutes after the shock. Afterward they were quite normal. It is evident that little or no damage was produced by the surge discharge under these conditions.

In the second group, five rats were suspended so that the surge traversed the entire length of the body. All five died despite the use of artificial respiration. After the shock heart beat was demonstrated in only one of the five rats. This rat made a few attempts to breathe but although artificial

TABLE III.

*Results of Surge Shocks on Rats.*

| Group. | Path of Surge. | No. | Recovery. | Breathing. | Heart Beat. | Resuscitation. |
|---|---|---|---|---|---|---|
| 1 | Surge entered at: | | | | | |
| | Head | 3 | 3 | Normal | Normal | None needed |
| | Shoulders | 3 | 3 | Normal | Normal | None needed |
| | Rump | 1 | 1 | Normal | Normal | None needed |
| 2 | Tail to head | 4 | 0 | None | None detected | Failed |
| | Back of head to tail | 1 | 0 | Feeble | Feeble | Failed |
| 3 | Back of neck to tail | 4 | 0 | Feeble in 1; none in others | Feeble | Failed |
| 4 | Shoulders to tail | 4 | 3 | 1 normal; others feeble | Normal | Not needed on 1; successful on 2. |
| 5 | Middle of back to tail | 4 | 3 | Normal | Normal | Failed on the 1 requiring it. |
| | Right fore-leg to tail | 3 | 2 | 1 normal; others feeble | | Not needed on 1; 1 successful; 1 failure |
| | Left fore-leg to tail | 4 | 1 | 1 normal; others feeble to none | | Not needed on 1; others failure |
| 6 | Back of neck to abdomen | 4 | 1 | Feeble to none | Feeble | Successful on 1 |

In Group 1 experiments the rats lay on the ground plate. All other experiments were made with the rats suspended.

respiration was continued for a considerable time, it died. In these animals rhythmic tremors of the striated musculature were observed. These tremors were most marked in the hind-legs.

In the third group, the brain itself was not included in the pathway of the discharge but the brain stem and the areas controlling the heart and respiration lay close to the electrode. In the four animals tested the heart beat was again found to be affected by the discharge. Artificial respiration was used in all cases but none of the animals recovered. The injury to the heart was not as great as where the discharge traversed the entire length of the body. Nevertheless it proved fatal.

Four animals, Group 4, were tested with the surge entering at the level of the shoulder and passing from the tail to the ground plate. Three of these recovered and one died.

Under these conditions the portion of the brain controlling the heart and lungs did not lie in the direct path of the discharge. One animal breathed at once following the injury and recovered quickly. Another started breathing spontaneously but stopped and was saved by artificial respiration. The third was also resuscitated but the fourth, although it attempted to breathe, died. The hearts in these four animals all beat strongly following the surge discharge. Marked tremors were again noticed and in one animal the hind-legs were weak for an hour after the shock, it later became entirely normal.

A surge discharge was passed through four animals from the mid-thoracic region to the tail—Group 5. In all four the hearts beat strongly following the shock and they all breathed spontaneously. In one, however, the breathing ceased and it could not be resuscitated.

Several animals were tested by being suspended from one or the other of the fore-legs, the spark passing from the tail to the ground plate. The majority of these animals recovered quickly as may be seen from the table.

Group 6: One other current path was tried, the discharge entering at the back of the neck and leaving in the mid-abdominal region. Four animals were tested in this manner and artificial respiration was used in every case. Only a single animal, however, was saved. In these four animals the heart beat was weak following the discharge but improved considerably during the first few minutes. Clonic movements followed the passage of the discharge.

The discharge of the lightning generator produced tremors of the musculature in almost every case. The chests of the animals were expanded following the discharge and there was little evidence of the severe muscular contraction noticed in the experiments with direct and alternating current circuits. The heart of the rat is usually but little influenced by electric shock. In the earlier work there were very few instances in which the heart showed any injury following the electric shock. This was not true in the case of the lightning discharge. Here the action of the heart was definitely affected in a large number of the experiments. Either no heart beat could be detected or the heart was very feeble following the

discharge. However, there was no evidence of ventricular fibrillation.

These experiments with the surge generator also indicate clearly the importance of the current path through the animal and check the results already reported for the different current pathways. It is clearly evident that the damage to the organism is greater, the greater the amount of nerve tissue that lies in the current path. If the surge passed from the head to the tail none of the animals breathed. As the position of the electrode by which the animal was suspended was changed from the top of the head down the back, that is, as the brain and nerve centers were eliminated from the path of the current the chances of recovery became greater.

### DAMAGE TO THE NERVOUS SYSTEM.

As already stated autopsies were made of the animals and sections of their brains and spinal cords were examined by Langworthy.[7, 8, 9] To avoid post mortem changes the brains and spinal cords of the rats were removed directly after death and were immediately fixed in a suitable solution. The nervous systems of the animals used in all three of the series of experiments were studied. The material was cut into slices and examined with the unaided eye and later microscopic material was prepared which made possible the study of the nerve cells. The material available for study was not all derived from the experimental animals. The nervous systems of two men killed by electricity were also examined.

Numbers of the rats injured by contact with the alternating circuits showed a paralysis of the hind-legs that manifested itself directly after the accident. These animals were quiet inactive and could not be induced to eat. They never lived longer than two or three days. When studied after death it was found that the spinal cord was abnormally soft; an area of hemorrhage extended for a long distance longitudinally severing the nervous pathways. There was no hope for the recovery of the paralyzed animals.

Hemorrhages are probably due to the sharp rise in blood pressure which follows the breaking of the contact with an electric circuit. While the current is flowing through the

body the blood is squeezed out of the heart and arteries due to the contraction of the muscles of their walls, and collects in the veins. When the heart beat begins again this blood is forced back into the heart and arteries at once. This often overtaxes the capacity of the arteries and breaks occur in their walls. In these experiments, hemorrhages in the nervous system were responsible for the immediate or subsequent death of a certain number of animals subjected to contact with an electric circuit. They were much more common after contact with the alternating than with the continuous circuits. This may be due to the greater contraction of the muscles which occurs upon contact with an alternating current circuit. The number of hemorrhages increased with the increase of the voltage of the circuit.

Changes in the nerve cells were found even in those animals that died immediately following the shock. The changes were more marked after shocks from the higher voltage circuit than from the low voltage circuits. They were also more severe as a result of the continuous current shocks than those produced by the alternating current.

In order to facilitate the study of the nerve cell structures, they were stained with an analine dye. It is well known that certain portions of the cells have an affinity for basic dyes and others for acid dyes.

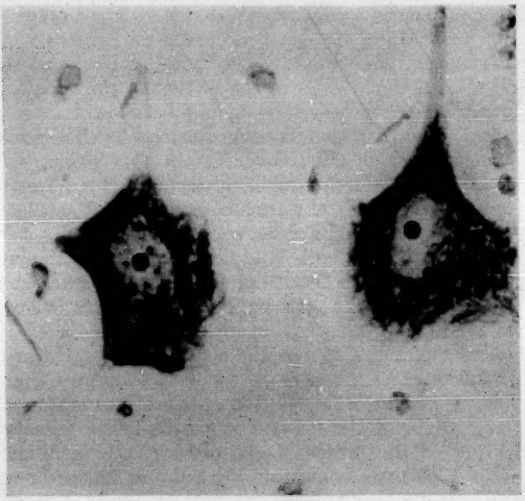
Figure 2 shows two normal nerve cells stained with a basic analine dye. As may be seen, the edges of the cells are not regular but are prolonged outward into angles which form the origin of the nerve fibers. The clear area which always lies in the center of the normal cells is called the nucleus. This space contains a black dot at its center which is known as the nucleolus. Around the nucleus there are fluffy granules filling the remainder of the cell, which are always arranged in this characteristic manner in normal cells. They are probably formed after death by the coagulation of some protein substance.

Nerve cells damaged by the current are shown in Fig. 3. The nucleus is no longer located in the center of the cell and the nucleolus is swollen. There is also evidence of loss of the granules so that only a few remain near the edges of the cell.

Figure 3 is typical of the damage observed in the brain of both rats and humans following an electric shock.

Not all of the nerve cells in any one group showed an equal amount of damage. Normal cells were scattered among those that had suffered great changes. After a study of many sections, it was believed that cells having potentialities of recovery could be differentiated from those that had been rendered completely and permanently functionless. The nucleus, as a rule, indicated the fate of the cell. If it shows marked damage the cell will die.

FIG. 2.



Normal nerve cells stained with a basic aniline dye.

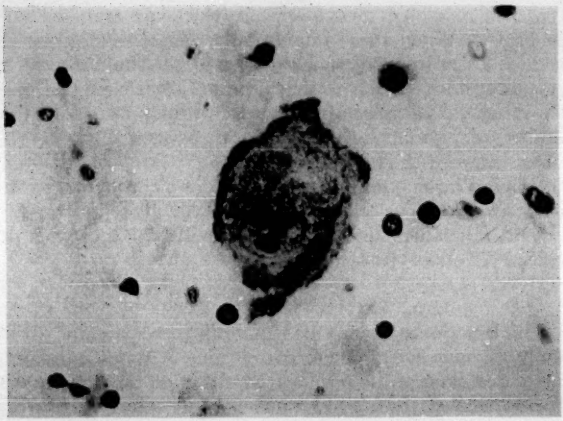
In animals that recovered from the immediate effects of the shock and were killed about a week later, the nerve cell changes were demonstrated with even greater clearness than in those which did not survive the shock. In the former were found to be many cells that were permanently damaged. There was also evidence of the repair of other cells in which the damage had not been so great.

The brains and spinal cords of the series of animals in

which the effects of the various current pathways had been investigated were also studied. In general the injury to the cells was confined to nerve tissue that lay in the direct pathway of the current.

The changes produced in the nerve cells by electricity are not specific and may be caused by other agents such as heat. It is well known that the body temperature rises rapidly if the circuit is closed for any length of time. Moreover, marked changes were found in the brain cells of a man who

FIG. 3.



Typical of the damage observed in the brains of both rats and humans following electric shock.

died after a contact of long duration with a 2,200-volt, 60-cycle circuit, although the current flowed from his arm to the legs.

In the experiments conducted with the impulse generator, the total amount of energy involved in the discharge was very small and there was no measurable rise in the body temperature. An examination of the brains and cords of these animals showed clearly that if they were traversed directly by the surge current, marked changes were produced in the cells. It was clear, therefore, that an electric current may produce profound changes in the nerve cells in cases

where heat is not a possible factor. In accidents where the period of contact is prolonged, it is without doubt true that the rise in the body temperature produces in itself marked alterations in the nerve cell structures. Morrison, Weeks and Cobb [10] have also studied the changes in the nervous systems of animals following electric shocks and their findings agree closely with those reported in this paper.

In addition to heat there is another cause which may affect cells lying outside of the current path. In accidents where the contacts are at points on the same arm or leg, the passage of the electrical current between these points gives rise to violent nerve stimuli which are transmitted to the brain. When these impulses are very strong they may produce a condition of shock due to hyperstimulation of the nervous system, similar to that produced by severe operations or injuries. Examples of this type of injury were found in a number of animals especially in those where the current flowed between the hind-legs.

When a large continuous current flows through the brain, injuries to the nerve cells are produced which are incompatible with life, the shrinkage of the cells being the most common evidence of this type of injury.

### CURRENT THROUGH THE HEART.

The heart of man may be thrown into ventricular fibrillation by the passage of an electric current. An investigation [11] was undertaken to determine the value of the current that actually flowed through the heart when contact at various points on the body was made with the circuit. The dog was chosen as the experimental animal because the heart of a dog is readily thrown into a permanent state of ventricular fibrillation by the application of weak currents.

The source of the current was a 60-cycle alternating supply circuit, ring, or through type, current transformers being employed to measure the current actually passing through the heart. The heart itself formed the primary winding of the transformer. The iron cores of these transformers were approximately square and .07 square centimeter in cross-sectional area. They were made of permalloy. Ring transformers of different sizes were constructed in order to take

care of the varying sizes of the hearts. Each ring was uniformly wound with several complete layers of enamel insulated copper wire which served as the secondary winding. The terminals of the secondary winding were connected across a potentiometer rheostat and the desired proportion of the voltage drop in this rheostat was fed into an amplifier, the output of which was a measure of the current flowing through the primary (in this case the heart) of the transformer. The operation of the transformer was carefully checked in a conducting bath, and the output of the amplifier was found to be proportional to the current actually flowing through the area inclosed by the ring.[12]

In order to insert the transformer the dogs were completely anæsthetized with morphia and ether. The chest was opened, artificial respiration maintaining normal lung operation. The heart was freed from its attachment to the diaphragm. The proper sized transformer was passed over the apex of the heart until it fitted snugly at the mid-region of the ventricles, where it was held in place by ligatures passing through the pericardium, a sack inclosing the heart. Then the pericardium was sewed fast to the diaphragm again at the location of its original attachment. Small insulated leads from the secondary were carried through the chest wall to their proper connections on the amplifier and the chest was closed in order to establish as nearly as possible normal conditions.

Several preliminary experiments were carried out and it was found that there was no change in the current distribution for a period of fully a half hour after death. Then experiments using different current pathways were made with the ring transformer encircling the heart, thus measuring the current that flowed through the heart parallel to the long axis of the body. In these experiments the total current through the body was varied in the different animals but in any given animal it was held constant throughout the test. In each of these experiments the electrodes were first placed on the head and tail and the total body current adjusted to the desired value and that through the heart read on the amplifier. The electrodes were then shifted to a new position, the total current through the animal brought back to its

proper value, and that through the heart measured. This was repeated until all the important current paths had been studied.

It was found that approximately 9.5 per cent. of the total current flowing parallel to the long axis of the body passed through the heart. Slightly more current flowed through the heart when a current entered at the right fore-leg and passed out at either hind-leg or tail than when it entered via the left fore-leg. This result checks the earlier experiments made on rats which have already been reported.

When the current path was from the head to either fore-leg only a small portion of the total current passed through the heart. No current through the heart could be detected when the path was from hind-leg to hind-leg. This result also confirms experimental data found with rats.

With a current path from fore-leg to fore-leg the current flows more or less transversley through the thorax. A few experiments were made with the two-inch ring transformer attached to the right side of the heart, fixing its plane approximately perpendicular to the current path. Under these conditions three per cent. of the total body current passed through the area inclosed by the transformer.

It is evident, therefore, that a much greater percentage of the total current passes through the heart when the current pathway is parallel to the long axis of the body than when it flows transversely. A larger current passes through the heart when contact is made with the right hand than with the left.

The current necessary to initiate fibrillation in the heart of a dog was measured in a number of cases. In all of these tests the electrodes were attached to the head and tail of the animal and the total currents gradually increased, using a five second shock at each value. After each shock the chest was opened and the condition of the heart visually determined. As could be expected there was considerable variation among the individual animals. In one case a current of 6 milliamperes through the heart was all that was required to initiate fibrillation. In another a value of 15 milliamperes was required. In most of the animals the value was 9 to 10 milliamperes and the average was 8.6 milliamperes.

### EFFECTS PRODUCED BY ELECTRIC SHOCK.

A number of factors of importance in cases of electric shock will be summarized below. The influence of the voltage has already been discussed as well as the effect of the current upon the striated musculature and the resistance of the body.

1. *Consciousness.*—A few individuals retain full consciousness while they are in contact with an electric circuit and are able to call for help. Others are rendered unconscious at once without making any outcry whatsoever. If the victim recovers, consciousness may return after a few seconds or minutes. Usually the victim is able immediately to resume his work, provided the injuries inflicted by the current are not severe. In some instances, however, the unconscious state passes into a deep coma which is interrupted by violent convulsions, terminating in death.

There are on record a number of accidents in which unconsciousness followed a shock between two fingers of the same hand, or two points upon the same leg. In such accidents no current flowed through the central nervous system and the action must have been due to the sudden shock and the resulting vasomotor reactions.

2. *Duration of Contact.*—The duration of the contact with the circuit is extremely important in determining whether an individual will survive or not. There is usually little data available in the cases of human accidents as to the length of the period during which the current flowed through the body. Fortunately, due to the violent contraction of the muscles when contact is made with high voltage circuits, the shock is usually of very short duration. On the other hand, in low voltage shocks, the person may be held in contact with the circuit and the current may flow for a considerable time. In the first series of experiments on animals in which they were subjected to shocks of varying voltage, the importance of the time factor is clearly demonstrated. In general the higher the voltage the shorter the time during which the circuit may remain closed and there be hope of resuscitation.

3. *Current.*—In human accidents the value of the current flowing is not usually known and it is possible to learn only the voltage of the circuit. In animal experiments this is not true as an ammeter may be inserted in the circuit and the current measured.

The sensitivity of various individuals to electric current varies widely. The threshold of sensitivity is from one-half to two milliamperes. Currents of eight to ten milliamperes are quite painful and at 20 milliamperes the contraction of the muscles is so great that the victim cannot release his hold on the circuit. Experiments by Weiss [13] demonstrated that in dogs a current of from 70 to 80 milliamperes flowing through the body would produce ventricular fibrillation of the heart. He showed that larger values of the current may cause a contraction of the muscles sufficient to inhibit all action in the heart. In such cases the heart usually resumes rhythmic beating when the circuit is opened. In humans an alternating current of from 90 to 100 milliamperes is considered dangerous.

Not only is the total current through the body of importance but also the current density must be considered. In their experiments with animals the authors found that a small animal could not recover from a given shock as readily as a much larger animal. This is, perhaps, one of the reasons for the belief that thin people are more susceptible to electric shock than large individuals.

4. *Effect Upon the Nervous System.*—Urquhart [14] in 1927 and Urquhart and Noble [15] in 1929 demonstrated that the passage of the current through the body might cause a block in the nervous system and inhibit respiration. If artificial respiration is promptly applied and continued for a sufficient time the respiratory center may have opportunity for recovery of its functions. The present experiments substantiate this theory. In the microscopic examination of the nerve tissues of animals, the injury to the nerve structure was clearly demonstrated. In those animals which could not be induced to breathe following the shock the cell damage was more marked, and in some instances the injury to the nerve cells was so severe as to be incompatible with life.

5. *Hemorrhages.*—Hemorrhages in the spinal cords of many of the rats caused paralysis of the hind-legs. Injuries of this type are not found in the case of human accidents.

In a number of animals, however, hemorrhages were also found both in the substance of the medulla oblongata and filling the fourth ventricle of the brain. Similar hemorrhages are common in legal electrocutions.

Bleeding following the shock was also observed in other portions of the body. That from the eyes was due to rupture of the blood vessels in the conjunctiva. In some of the experiments when artificial respiration was begun there was a rush of blood and frothy liquid from the nose and mouth of the animal. This was probably due to hemorrhages and edema in the lungs. Similar phenomena have been reported in the case of human accidents.

The hemorrhages found in the brain of the rats were seldom responsible for the death of the animals. Only those which distended the fourth ventricle, pressing on the respiratory center, and those occurring in the spinal cord were believed of sufficient magnitude to cause the death of the animal.

6. *Convulsions.*—In human accidents convulsions are occasionally recorded following an electric shock. They were observed in a number of the experimental animals, many of which were hypersensitive to all sensory stimuli after the shock. In a few cases there was evidence of disturbance to the vestibular mechanism as shown by the animals walking or running in circles.

7. *Priapism and Emission.*—Priapism occurred in many of the male rats shocked with the 1,000-volt direct current circuit and also in some later experiments with alternating current circuits. In these it persisted until the animal was killed a week or more later.

Emissions were very commonly observed in the males subjected to alternating current shocks. It was an almost universal occurrence at the higher voltages but was also found in more than 25 per cent. of the animals after contact for two seconds with a 15-volt alternating current circuit. It is probably caused by the strong contraction of the musculature and has been reported in a number of human accidents.

8. *Ventricular Fibrillation.*—The human heart seldom recovers spontaneously from the state of ventricular fibrillation. Some observers of electrical accidents estimate that the majority of the deaths are caused by this abnormality. The action of electricity upon the heart is, therefore, of greatest importance.

No specific method has as yet been developed for the

recovery of the fibrillating heart in man but some experimental work by Hooker [16, 17] is illuminating and interesting. Hooker, in a number of experiments on dogs, demonstrated that it was possible to stop the fibrillation of the heart by the injection of a potassium chloride solution in the carotid arteries. The injection of this solution totally inhibits all contraction of the heart musculature. The solution is then washed out with physiological saline solution and the heart resumes its normal rhythm.

9. *Permanent Disability Following Electric Shocks.*—Only a very small percentage of individuals who have recovered from an electric injury show any permanent disability. Extensive burns following the contact may be a long time in healing and nerve ends sometimes get caught in the scar tissue, thus producing a lasting irritation. Cataracts of the eyes are found in a few instances. Some individuals show an instability of the nervous system for a considerable time. How much of this is caused by actual damage to the nerve cells and how much should be classed as neurosis is difficult to say.

Panse [18] has gathered some 29 cases in which he reports muscular atrophy following electrical accidents. The atrophy may develop soon after the injury or after several months. He reports that it is usually preceded by pain and abnormal sensations in the extremity and accompanied by vascular disturbances. These data of Panse are very interesting but they must be examined rather critically. The abnormalities that he reports follow the shocks after latent periods of weeks or months. In the literature of England and the United States no similar cases of atrophies following electric shock have been found. It is important, therefore, that these late effects be watched for carefully in the future.

### CAUSES OF DEATH.

It is recognized that the heart and the respiratory center in the medulla are particularly susceptible to injury with electric currents. In our experimental work with animals and in reports of the accidents in the field, it is evident that death from electric shock may occur from a number of different causes. Death by asphyxiation may be caused by

the prolonged contraction of the muscles during the passage of the current through the body. A second cause is ventricular fibrillation of the heart, usually believed to be induced by low voltage shocks. Death may be caused by the destruction of nerve cells of the respiratory center incompatible with life. A fourth cause of death is the increase above the safe limits of the body temperature by the Joule effect of the current flow. Burns and other complications may also result in death.

Jellinek [19] stresses the fact that in electrical accidents death is often only apparent. Artificial respiration should be begun immediately and it should be continued either until the patient recovers or until the cessation of life is an actuality as evidenced by the onset of rigor mortis. Malachlan [1] reports a successful case of resuscitation following an eight-hour application of the Schaefer prone pressure method.

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# DETERMINATION OF "AVERAGE PARTICLE SIZE" FROM THE SCREEN-ANALYSIS OF NON-UNIFORM PARTICULATE SUBSTANCES.

BY

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## INTRODUCTION.

It is now generally recognized that the "size" of a non-uniform particulate substance is not completely defined by a single mean value, such, for example, as the arithmetic mean diameter. On the contrary, several *average diameters* are necessary to a full mathematical description of the "size" of such materials. The significance of these size parameters was first pointed out by Perrott and Kinney (1) and has been discussed fully by Green (2) who also introduced the mathematical shape factors for defining the geometric shape of irregular particles. According to Green's definition, "an *average diameter* is the diameter of a hypothetical particle which in some way represents the total mass of particles" (loc. cit., p. 714). Thus, we may have a series of parameters representing diameter, surface area, volume, specific surface, etc. The several *average diameters* necessary to a complete definition of particle size are presented in Table I, col. 3. These equations are general in form and may be employed regardless of the shape of the size-frequency distribution curve of the non-uniform material.

It will be observed that the parameters are functions of two factors: particle diameter and the numerical frequency of particles of a given diameter, $d$; hence, in order to calculate their respective values for a given sample, the size distribution data must be expressed in terms of frequency by *count*. This requirement is met when the distribution curve is obtained direct from the microscopic measurement of a large number of representative particles. There are several indirect means of classifying the particles into different size-groups

TABLE I.

*Mathematical Definitions of the Average Diameters of Non-uniform Particulate Substances in Terms of the Parameters of the Size Distribution Curves by Count and by Weight.*

| Average Diameter. | Symbol. | Mathematical Definition. | Equivalent Logarithmic Value in Terms of Statistical Parameters of Distribution Curves. | |
|---|---|---|---|---|
| | | | By Count ($M_g$ and $\sigma_g$). | By Weight (screen analysis) ($M_g'$ and $\sigma_g'$). |
| 1 | 2 | 3 | 4 | 5 |
| Geometric Mean | $M_g$ | $\text{antilog}\left(\frac{\Sigma n \log d}{\Sigma n}\right)$ | $\log M_g$ | $\log M_g' - 6.9078 \log^2 \sigma_g'$ |
| Arithmetic Mean | $\delta$ | $\left(\frac{\Sigma nd}{\Sigma n}\right)$ | $\log M_g + 1.1513 \log^2 \sigma_g$ | $\log M_g' - 5.7565 \log^2 \sigma_g'$ |
| Specific Surface | $d_s$ | $\left(\frac{\Sigma nd^{-1}}{\Sigma n}\right)^{-1}$ | $\log M_g - 1.1513 \log^2 \sigma_g$ | $\log M_g' - 8.0591 \log^2 \sigma_g'$ |
| Surface Area | $\Delta$ | $\left(\frac{\Sigma nd^2}{\Sigma n}\right)^{1/2}$ | $\log M_g + 2.3026 \log^2 \sigma_g$ | $\log M_g' - 4.6052 \log^2 \sigma_g'$ |
| Volume | $D$ | $\left(\frac{\Sigma nd^3}{\Sigma n}\right)^{1/3}$ | $\log M_g + 3.4539 \log^2 \sigma_g$ | $\log M_g' - 3.4539 \log^2 \sigma_g'$ |
| Surface * Area per Unit Vol. | $D^3/\Delta^3$ | $\left(\frac{\Sigma nd^3}{\Sigma nd^2}\right)$ | $\log M_g + 5.7565 \log^2 \sigma_g$ | $\log M_g' - 1.1513 \log^2 \sigma_g'$ |

* This diameter gives the specific surface for the sample as a whole; it should not be confused with $d_s$, the diameter of the hypothetical particle having *average* specific surface.

frequently employed, however, which give the distribution by *weight*. A method of this character commonly used in the case of fairly large particles is by sieving through metal cloth screens of graduated mesh size, and determining the percentage by weight of the material retained on each screen. For the reason given above, the data thus obtained cannot be used directly in the calculation of the various average diameters. The weight distribution curve, however, bears a definite relation to the curve obtained by direct count (since weight is simply a function of size and count), and with the aid of this relationship, suitable equations may be set up by means of which one is able to calculate the various average diameters from the data obtained by the ordinary screen analysis. The necessary equations are developed in the present paper.

### STATISTICAL DESCRIPTION OF PARTICLE SIZE.

It has been pointed out by Drinker (3) and more recently by Loveland and Trevelli (4) that the size-frequency curves of non-uniform particulate substances produced by crushing, chemical precipitation and other means have the shape of the logarithmic probability curve. This curve is rigidly defined by the well-known statistical parameters, the geometric mean, and the standard geometric deviation and since the average diameters defined in Table I are all functions of the size-frequency curve, it follows that they can be calculated from these statistical measures. The necessary equations, developed by Hatch and Choate (5) are presented in Table I, col. 4.

The advantage of the statistical description of particle size lies in the fact that the "size" is completely defined by two parameters, $M_g$ and $\sigma_g$, instead of a series of average diameters, thus simplifying the mathematical description.

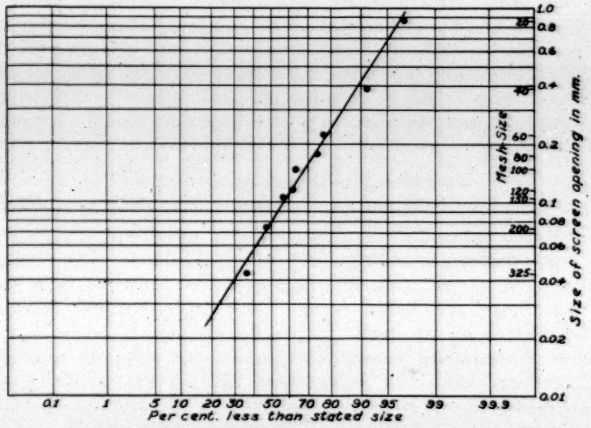
A graphical method of determining the geometric mean and standard geometric deviation has also been described (loc. cit.) which reduces the time and labor involved in their calculation. In this method logarithmic-probability paper is employed on which the summation or integral of the distribution data plots as a straight line.

### DETERMINATION OF PARTICLE SIZE FROM SCREEN ANALYSIS.

*Relation between Frequency Distribution Curves by Count and by Weight.* It can be shown that if the size-frequency

curve by count follows the logarithmic probability law, then the distribution curves in terms of surface area, weight, or any other functions of size and count will have the same form. This accounts for the good straight-line plots on logarithmic probability paper, given by screen analysis of sands, particles

FIG. 1.




Typical screen-analysis data plotted on logarithmic probability paper.

obtained by crushing, etc. (see Fig. 1). Thus, we may write the equation for the size-frequency curve by weight:

$$\rho\nu nd^3 = \frac{\Sigma\rho\nu nd^3}{\log \sigma_g' \sqrt{2\pi}} e^{-(\log d - \log M_g')^2/2 \log^2 \sigma_g'}, \qquad \text{I}$$

where $d$ = particle size retained on each screen,
$n$ = number of particles retained on each screen,
$\nu$ = volume shape factor,
$\rho$ = density of the material,
$M_g'$ = geometric mean of the curve, i.e., by weight,
$\sigma_g'$ = standard geometric deviation of the curve.

It is evident that $\rho\nu nd^3$ equals the weight of the material

retained on each sieve, and that the total weight of the sample is given by $\Sigma\rho\nu nd^3$. They correspond to the values $n$ and $\Sigma n$ in the equation of the size-frequency curve by count.

We may also write:

$$\log \delta' = \log\left[\frac{\Sigma(\rho\nu nd^3)d}{\Sigma\rho\nu nd^3}\right] = \log M_g' + 0.5 \log^2 \sigma_g', \qquad \text{II}$$

where $\delta'$ = arithmetic mean diameter by weight. This follows from the definition of the arithmetic mean diameter and its mathematical equivalent in terms of the statistical parameters, $M_g'$ and $\sigma_g'$ (see Table I, col. 4). Equation II may be written:

$$\log \frac{\Sigma nd^4}{\Sigma nd^3} = \log M_g' + 0.5 \log^2 \sigma_g'. \qquad \text{III}$$

But,

$$\log D^3 = \log\left(\frac{\Sigma nd^3}{\Sigma n}\right) = 3 \log M_g + 4.5 \log^2 \sigma_g,$$

where $Mg$ and $\sigma g$ are the statistical parameters of the size-frequency curve by count (see Table I). Adding this expression to equation III, we obtain

$$\log\left(\frac{\Sigma nd^4}{\Sigma n}\right) = \log M_g' + 0.5 \log^2 \sigma_g' + 3 \log M_g + 4.5 \log^2 \sigma_g. \qquad \text{IV}$$

The expression, $\log\left(\frac{\Sigma nd^4}{\Sigma n}\right)$, however, is the fourth moment of the normal logarithmic probability law, and we may therefore write:

$$\log \frac{\Sigma nd^4}{\Sigma n} = 4 \log M_g + 8.0 \log^2 \sigma_g.$$

Substituting this value in equation IV, we get:

$$\log M_g' = \log M_g + 3.5 \log^2 \sigma_g - 0.5 \log^2 \sigma_g'. \qquad \text{V}$$

Entering this value of $Mg'$ in equation I and also substituting in place of $n$, the value given by the size-frequency distribution by count (5), it can be shown that $\sigma g'$ equals $\sigma g$,[1] from which

[1] This means that the summation curves by weight and by count will plot as parallel lines on logarithmic probability paper, a fact which is borne out experimentally as well as theoretically.

we may write:

$$\log M_g = \log M_g' - 3.0 \log^2 \sigma_g'. \qquad \text{VI}$$

Transferring to logarithms to the base 10, this becomes:

$$\log M_g = \log M_g' - 6.9078 \log^2 \sigma_g'. \qquad \text{VIa}$$

By means of this relationship we may now define the various average diameters in terms of the statistical parameters of the distribution curve obtained by the screen analysis, that is to say, in terms of $M_g'$ and $\sigma_g'$. These equations are presented in Table I, col. 5.

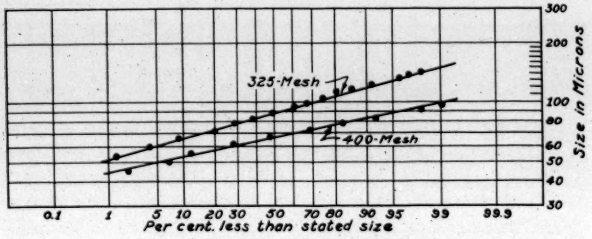
*Calibration of Screens.* In the foregoing discussion, the size of the particles retained by each screen was not defined. For mathematical purposes, in order to equate the parameters given by the screen analysis with those obtained by direct microscopic measurement, the screens were considered simply as mechanical aids for the purpose of dividing the sample into size-groups. In statistical practice, when dealing with grouped data, the size of the material falling within a given class interval (size-group) is taken equal to the median size of the group, which in the present case would be the median size by weight. Microscopic examination of the screened samples, however, reveals the fact that the distribution curves for the individual screens follow the logarithmic-probability law. The median group size therefore becomes the geometric mean size by weight, which may be calculated by means of the transformation equation (VIa) from the parameters $M_g$ and $\sigma_g$ of the size-frequency curve obtained by direct microscopic measurement of the screened sample.

The measurements should be made on samples obtained according to the standard technique employed in making actual screen analysis and the results given by one kind of material will not necessarily apply to other substances made up of particles of different geometric shape. Calibration curves for the 325 and 400-mesh sieves, obtained in this manner with crushed limestone are shown in Fig. 2.

This method of calibrating screens differs from that commonly employed in which it is assumed that the act of screening divides the particles into size groups which join at their limits but do not overlap. The "size of separation" is

taken equal to the dimension of the screen opening or may be calculated by some arbitrary method. Actually a definite separation is not obtained but on the contrary, particles of a given diameter may be found on three or four different screens. Hence, the "size of separation" has no physical meaning and although it is related to the geometric mean size by weight, the relationship depends upon the definition

FIG. 2.




Calibration of 325 and 400-mesh screens—size-frequency curves for limestone dust actually retained, employing standard screening technic.

of the former and varies with the nature of the sample. On the other hand, the calibration obtained by the proposed method is based upon the size of the material actually retained (and weighed) and does not depend upon arbitrary assumptions.

### APPLICATION.

This method of treating screen analysis data is valuable for two reasons: first, it makes possible the use of the weight-distribution curve as a means of calculating the fundamental parameters, $M_g$ and $\sigma_g$, as well as the various average diameters of the sample; second, by means of the transformation equation, the weight-distribution data given by the screen analysis of the coarser portion of a sample and the frequency distribution data obtained by direct microscopic measurement of the finer material, can be joined to give a complete curve for the entire sample. Illustrations of these two applications follow.

The results of the screen analysis of a sample of crushed

limestone are given in Table II, together with the screen sizes obtained by the above method of calibration. For the purpose of plotting, the percentages by weight less than the

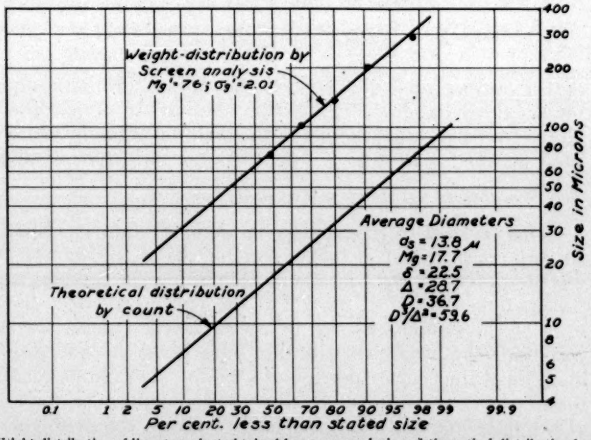
TABLE II.

*Screen Analysis of a Sample of Crushed Limestone.*

| Screen Size. | Calibration Size in Microns. | Percentage by Weight. | | |
|---|---|---|---|---|
| | | Passing. | Retained. | Less than Calibration Size. |
| 400 mesh..... | 72 | 40 | 17 | 48.5 |
| 325 mesh..... | 100 | 57 | 17 | 65.5 |
| 200 mesh..... | 136 | 74 | 13 | 80.5 |
| 150 mesh..... | 199 | 87 | 8 | 91.0 |
| 100 mesh..... | 282 | 95 | 5 | 97.5 |

median screen sizes have been calculated [2] and are given in the last column of the table. The resulting summation curve and its statistical parameters, $M_g'$ and $\sigma_g'$, are given in Fig. 3,

FIG. 3.




Weight-distribution of limestone dust obtained by screen analysis and theoretical distribution by count, calculated by means of transformation equation VIa. (Data from Table II.)

[2] Since the calibration size is taken as the median value by weight of the material retained, the percentage by weight less than this size is equal to the percentage passing the screen plus one-half of that retained.

together with the theoretical curve of the distribution by count, obtained by means of the transformation equation (VIa). The average diameters of the sample, calculated by means of the proper equations (Table I, cols. 4 and 5) from the parameters of either curve are also given.

The results obtained from the screen analysis of a finer sample of limestone are given in Table III. Less than 10

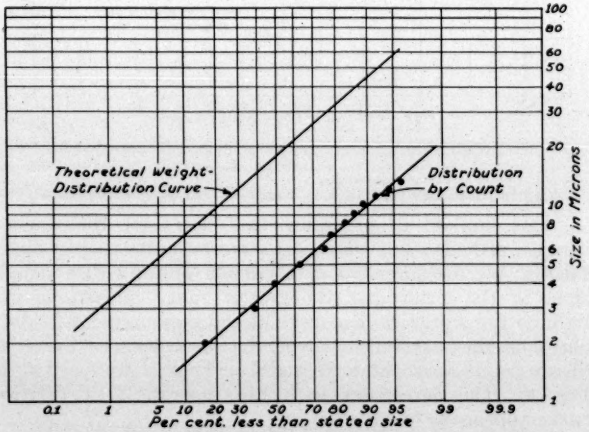
TABLE III.

*Screen Analysis of Sample of Fine Limestone Dust.*

| Size. | Per cent. by Weight Retained. |
|---|---|
| 200 mesh | 0.9 |
| 325 mesh | 3.6 |
| 400 mesh | 4.9 |
| Passing 400 mesh | 90.6 |

per cent. of the sample was classified by the screens and the data thus obtained could not therefore be used accurately to determine the size distribution of the entire sample. In order to complete the analysis, it was necessary to measure microscopically the size of the material passing the smallest screen. The results of the microscopic measurements of the fine

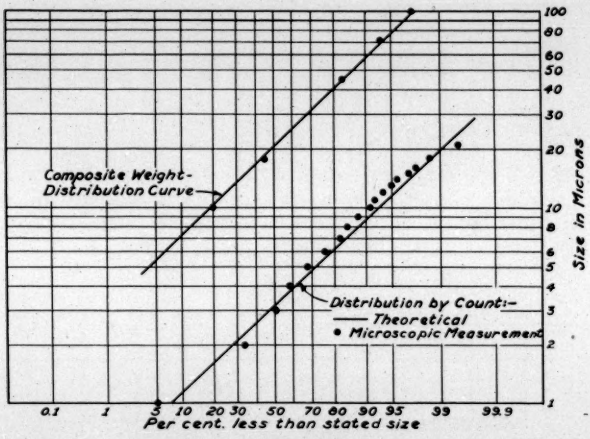
FIG. 4.




Analysis of sample of fine limestone dust. Size-frequency curve of material passing 400-mesh screen, obtained by direct microscopic measurement and theoretical curve of the distribution by weight.

material are shown in Fig. 4 together with the theoretical weight-distribution curve. Combining the values for selected sizes given by the latter curve with the data for the three screens (Table III) the distribution by weight for the entire sample was constructed (see Table IV). These data are plotted in Fig. 5, together with the theoretical curve of the distribution by count calculated from the parameters $M_g'$ and $\sigma_g'$.

FIG. 5.




Composite curve of distribution by weight of sample of fine limestone dust (data from Table IV).

Size-frequency curve calculated from weight-distribution curve and compared with distribution obtained by direct microscopic measurement.

This method of obtaining the "size" of the original sample, although not simple, is more accurate than a direct microscopic measurement of a portion of the entire sample since in the latter case the greater range in particle size reduces the statistical accuracy of the measurements. As a check on this method, however, the size-frequency curve by direct count was obtained and the results are plotted in Fig. 5. The agreement with the theoretical distribution curve appears to be satisfactory.

TABLE IV.

*Percentage Weight-Distribution of Fine Limestone Dust.*

Composite of Data from Screen Analysis (Table III) and Microscopic Measurement of Material Passing Finest Screen.

| Size in Microns. | Per cent. by Weight Less than Stated Size. |
|---|---|
| 10.0 [1] | 20 [1] |
| 17.7 | 45.3 [2] |
| 72.0 [3] | 93.05 |
| 100.0 [3] | 97.3 |

**SUMMARY.**

The size distribution data obtained by screen analysis of a non-uniform substance cannot be used directly in calculating the various *average diameters* of the material since this method of analysis gives the distribution in terms of weight rather than count. The distribution curve by weight however bears a definite relation to the regular size-frequency curve and suitable transformation equations are presented by means of which one is able to calculate the various *average diameters* from the parameters of the curve given by the screen analysis. The screens are calibrated in terms of the actual size of the material retained rather than the dimensions of the screen openings or an arbitrary method of calculating the "size of separation."

**REFERENCES.**

1. The Meaning and Microscopic Measurement of Average Particle Size. G. St. J. Perrott and S. P. Kinney. *Jour. Am. Cer. Soc.*, 1923, **6**, 417.
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3. The Size-Frequency and Identification of Certain Phagocytosed Dusts. P. Drinker. *Jour. Ind. Hyg.*, 1925, **7**, 305.
4. Mathematical Methods of Frequency Analysis of Size of Particles. R. P. Loveland and A. P. H. Trivelli. JOUR. FRANKLIN INST., Aug. and Sept., 1927.
5. Statistical Description of the Size Properties of Non-Uniform Particulate Substances. T. Hatch and S. Choate. JOUR. FRANKLIN INST., March, 1929, pp. 369–387.

[1] This value was obtained as follows: referring to Fig. 4, we see that 22 per cent. by weight of particles passing the 400 mesh screen were less than 10 $\mu$ in diameter and since 90.6 per cent. of the total sample passed the 400 mesh screen, this represents 20 per cent. of the original.

[2] 50 per cent. of 90.6 per cent.

[3] Calibration sizes of the 400 and 325 mesh screens.

**The Art of Damascening.**—The term "Damascene" as applied to steel has a double meaning. It may refer to a steel whose surface shows an alternation of light and dark bands. Such markings persist throughout the metal and usually are secured by welding and fusing together steel strips of different appearance and composition. A more modern definition of Damascene is that of inlaying steel with precious metals. As the name implies this art is supposed to have originated in the city of Damascus and it was from there the first articles were brought to Europe by the Crusaders.

Damascening was introduced into Spain by the Moors and probably is the only country where the art is regularly practised today. JOHN W. RADU (*Brass World*, Vol. 28, p. 177) describes a visit to Eibar, a little city in the Pyrenees, where much of the present day Damascene work is being done. The first step consists in making scratches in the surface of the steel in accordance with some chosen design. In these scratches light gold wire and gold leaf are laid. When heavy gold wire is to be used a half-round groove is chiseled into the steel and then undercut so as to give a dovetail cross-section.

The moderately priced inlay work is outlined with fine wire (some of it finer than a hair) and filled in with heavy gold leaf. None of the gold is below twenty-two carat and usually is twenty-four. Using the lower carat permits a variation in the color of the gold due to its alloying with other metals. The color range may consist of the yellow of pure gold, the red of the copper alloy and the green of the silver alloy. For further contrast, pure white silver occasionally is used.

The higher grade work does not utilize gold leaf, the design being both outlined and filled in with wire. Heavy wire is used where high relief in the design is desired. Once the design is completed the wire is burnished and chased. Following these operations the article is given a chemical treatment (the details are kept a trade secret) which produces a fine black finish on the steel. The gold is not affected.

All damascene designs are made free hand on the metal itself. In the smaller pieces the dragon holds a prominent position. There is also an extensive use of Arabic characters and design, an influence remaining from the original Moorish creators of this art. In cleaning these objects, the soiled marks are removed by moistening with a little oil and afterwards dried with fresh bread. A linen cloth or a brush never should be used.

C.

# THE RÔLE OF DISSOLVED GASES IN DETERMINING THE BEHAVIOR OF MINERAL INSULATING OILS.

BY

**F. M. CLARK,**

General Electric Company, Pittsfield, Mass.

ABSTRACT.

The characteristics of gas solution in mineral oil are discussed. Data covering the changing gas solubility with temperature and pressure are given.

The dielectric strength of oil is shown to be dependent on the kind and amount of its dissolved gas. The dielectric strength–gas content of oil bears a close relation to the recognized dielectric behavior of air itself. It is suggested that the usual dielectric strength of oil measures only the ease of oil "gassing" which may be dependent in part at least, on dissolved impurities.

The solubility of dissolved gas is of importance in the application of mineral insulating oils in electrical design. It is especially important that a clear conception of changing solubility under varying temperatures and pressures should be had if the formation of gas pockets is to be avoided in service. Of equal importance is the question of dissolved gases in relation to the dielectric strength of mineral oil. It is well known that the presence of "suspended" gas bubbles lowers the dielectric strength. It is not so clearly evident that dissolved gases also play a prominent part in determining the resistance of a mineral oil to electrical failure.

Air is perhaps the most important gas whose solubilities are concerned in commercial practice. All other gases may vary in their solubilities to a greater or less extent as compared to air, but their effects are of the same nature. The present article is therefore largely confined to a review of the solubilities of air and its constituent gases, oxygen and nitrogen. It is believed that the conclusions drawn from the study of these gases can be generally applied.

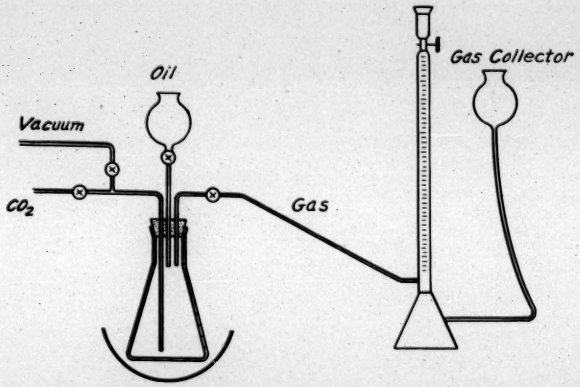
## STUDY OF GAS SOLUBILITY IN MINERAL OI

### Method of Test.

Various methods of test are possible in determining the gas dissolved in mineral oil. Throughout this paper a

vacuum-carbon dioxide displacement method has been used. By this scheme, the system is carefully freed from oxygen and nitrogen (air) using carbon dioxide, and then evacuated. The vacuum is broken by the slow admission of oil (semi-spray). The system and oil are then carefully blown out with pure carbon dioxide gas. The gas is collected over potassium hydroxide solution is the usual way. The scheme of set-up is shown in Fig. 1.

FIG. 1.




Apparatus used to determine the kind and amount of dissolved gas in mineral oil.

**Expression of Test Results.**

It is believed that the results can be best expressed by reducing all gas volumes to 25° C. and 760 millimeters pressure and basing all per cent. solubility values on the oil at the temperature of the test. This introduces considerations indicated by the following example.

**Example.**

Mineral oil tested at 100° C. for its dissolved air content.

Per cent. air at 100° C., 760 millimeters pressure, dissolved in oil at 100° C.—11.6.

Per cent. air reduced to 25° C., 760 millimeters pressure dissolved in oil at 100° C.—10.6.

Per cent. air reduced to 25° C., 760 millimeters pressure dissolved in 100° C. oil whose volume has been corrected to 25° C.—11.3.

**Air Solubility in Mineral Oil.**

The volume of gas dissolved in mineral oil depends not only on the type of gas involved but on the mineral oil as well. It has not been clearly demonstrated to date what oil factors determine the extent of gas solubility. Presumably the source of the oil (paraffinic or asphaltic) as well as the oil density is of considerable importance. The degree and type of oil refinement may also be of major effect. That all oils do not possess an equal ability to dissolve air either at room temperature or 100° C., is seen from Table I.

TABLE I.

*Air Solubility in Mineral Oil.*

| Viscosity of Oil in Saybolt (Universal) Seconds. | Type Oil. | Testing Temperature. | % Dissolved by Volume Under Atmospheric Conditions. | | |
|---|---|---|---|---|---|
| | | | % Nitrogen. | % Oxygen. | % Air. |
| 100″ (37.8° C.)..... | Mixed | 25° | 4.6 | .6 | 5.2 |
| 100″ (37.8° C.)..... | Asphaltic | 25° | 6.2 | 2.1 | 8.3 |
| 150″ (100° C.)..... | Paraffin | 100° | 6.4 | 1.2 | 7.6 |
| 150″ (100° C.)..... | Asphaltic | 100° | 4.64 | .16 | 4.8 |

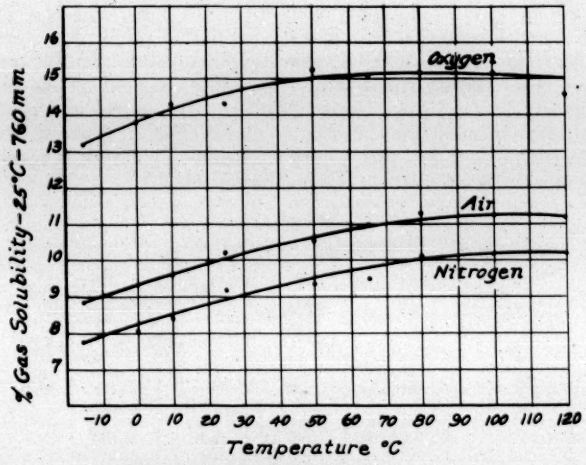
*Note:* Per cent. volume of gas dissolved is based on gas volumes reduced to 25° C., 760 mm. mercury pressure with oil volumes at temperature of test.

**The Effect of Temperature on Gas Solubility in Mineral Oil.**

With increased temperature mineral oils of the transformer type dissolve increased amounts of air. This is shown in Fig. 2. That the increased solubility is not due to an increase in oil volume with temperature is shown in Fig. 3. With an 8 per cent. expansion in oil volume, a 26 per cent. increase in air solubility is obtained. The oil with a 100° C. rise in temperature from − 15° C. as a base, therefore (maximum temperature 85° C.), takes up 18 per cent. more air than can be accounted for as a result of increased oil volume. This increased solubility is not accomplished by equally distributed increases in both the dissolved oxygen and nitrogen. As shown in Fig. 4, the ratio of dissolved nitrogen to oxygen

changes. At $-15°$ C. the nitrogen-oxygen ratio is 2.1. At 85° C. the ratio has increased to 2.46. This more rapid increase in nitrogen solubility is shown clearly in the curve of Fig. 3.

FIG. 2.




The effect of temperature on gas solubility in transformer oil.
Oil temperature—as stated.
Barometer—corrected to 760 mm.
Gas volume—corrected to 25° C.
Oil conditioning—4 hours at temperature given.
Oil volume—$3\frac{1}{4}$" deep, 36 sq. ins. surface area.

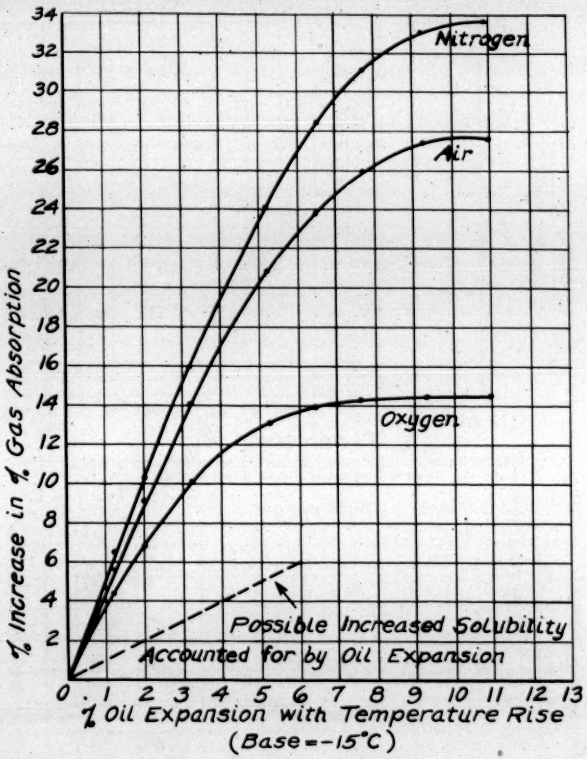
**Gas Solubility as a Function of Gas Pressure.**

The solubility of gas in mineral oil would be expected to change with pressure in accordance with the usual gas laws. All data available confirm this expectation. Figure 5 illustrates typical data for gas solubilities in transformer oil below atmospheric pressure, measured at 25° C.

**Phenomena of De-aëration.**

It is generally recognized that de-aëration demands careful technique if all dissolved air is to be removed. The application of a vacuum on a body of still oil de-aërates the oil only

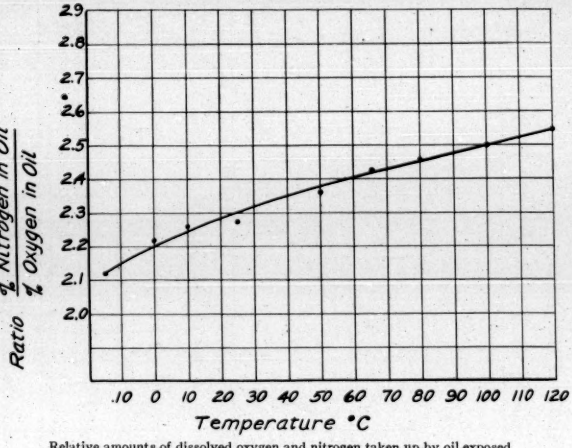
FIG. 3.


Nitrogen
Air
Oxygen
Possible Increased Solubility
Accounted for by Oil Expansion
% Increase in % Gas Absorption
% Oil Expansion with Temperature Rise
(Base = -15°C)
0 1 2 3 4 5 6 7 8 9 10 11 12 13
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34

Relation between gas solubility and oil expansion with temperature.

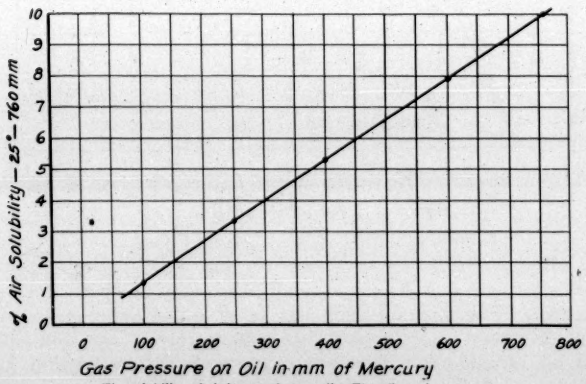
after long-time intervals. Usually the oil to be de-aërated is heated. For thick oils this may be of advantage because of the decreased viscosity at higher temperatures. For thin oils of the transformer type, high temperature application is probably of less advantage because of the increased air solubility with increased temperature. Should the tempera-

FIG. 4.




Relative amounts of dissolved oxygen and nitrogen taken up by oil exposed to air at temperature shown. Based on Fig. 2.

FIG. 5.

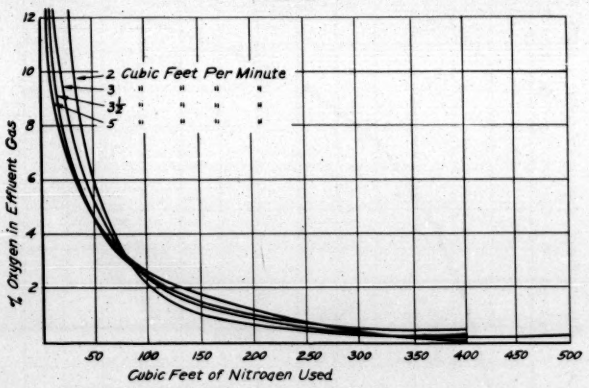



The solubility of air in transformer oil. The effect of pressure.
*T*—25° C. (for gas and oil).
*P*—760 mm. for gas volume.

ture be carried sufficiently high, however, so that the oil vapors can be used as "sweeping out" gases, the effect of temperature is advantageous. Usually the temperature is not raised to a sufficiently high value to take advantage of this effect. The best method of de-aëration is by oil spraying in a vacuum. This is efficient. Almost as efficient and of more easy application is the method of gas bubbling. Wherever possible, unless vacuum spraying be available, this method is recommended for removing the dissolved oxygen from mineral oil.

The rate of removal of oxygen from transformer oil has been studied in actual transformer set-up. The study has been based on the oxygen content of the emergent nitrogen gas which was bubbled through the oil in order to produce de-oxygenation. The results are shown in Fig. 6. In the tests

FIG. 6.




The removal of oxygen from transformer oil by nitrogen gas displacement. Procedure—Nitrogen gas bubbled through the oil at rate shown, under atmospheric conditions.

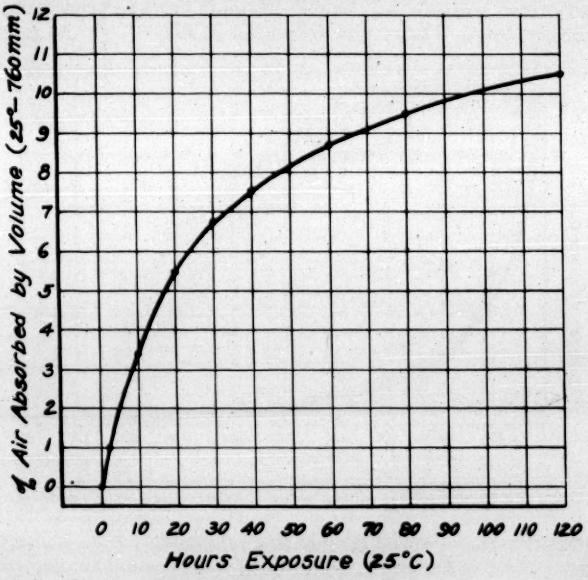
made, the transformers contained approximately 1,000 gallons of oil which at the start of the run held the normal amount of dissolved oxygen at room temperature. Although in the data of Fig. 6 the runs were not carried to the complete elimination of oil-dissolved oxygen, that only a negligible

amount remained in the oil was evident from the fact that the gas over the oil showed no tendency to increase amounts of oxygen even after standing at room temperature for periods of approximately one week.

### THE RATE OF RE-SOLUTION OF AIR BY DE-AËRATED OIL.

From the fact that air is difficult to remove from still oil, it is frequently concluded that its re-solution is likewise a slow and difficult process. The contrary is true. The re-solution of air by de-aërated oil is rapid, the exact rate being dependent on the ratio of oil depth to volume, oil agitation and other testing factors.

FIG. 7.

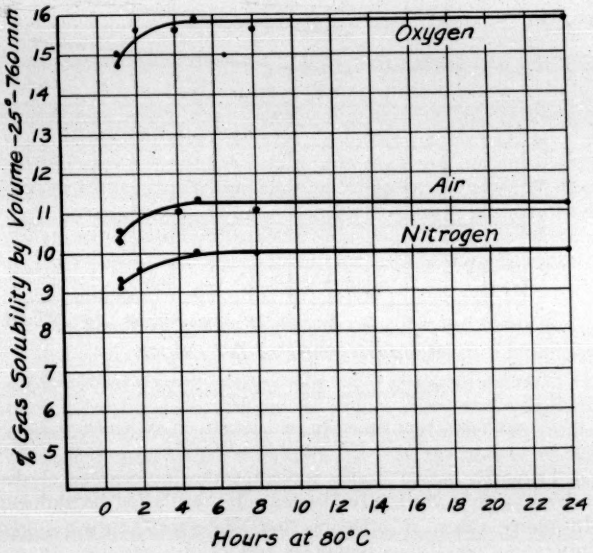



Rate of re-solution of air in transformer oil at 25° C.
Oil surface—8/10 sq. ins.
Oil depth—11 inches.
Temperature—25° C.
Barometer—760 mm. mercury.

Figure 7 shows the rate of re-solution at 25° C. for a body of still oil, .8 sq. in. surface area, and 11 in. deep (surface to depth ratio of .07).

Figure 8 shows the speed of air re-solution at 80° C. for a body of still oil, 36 sq. in. in surface area, and $3\frac{1}{4}$ in. deep (ratio of surface to depth of 11.0).

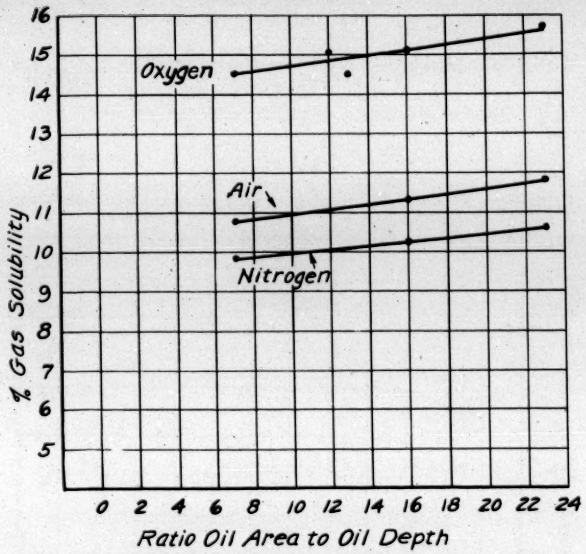
FIG. 8.




Gas solubility increase in 80° C. oil as a function of time exposure.
Oil—transformer oil at 80° C.
No circulation of oil.
Gas volume corresponding to 25° C.—760 mm.
Oil volume—$3\frac{1}{4}$" deep, 36 sq. in. area.

The effect of surface to depth ratio is shown in Fig. 9. With a fixed time for re-solution of one-half hour at 100° C.. the amount of gas re-dissolved is a linear function of surface to depth ratio.

FIG. 9.




The effect of surface area to depth on gas re-solution in degassed transformer oil. Oil heated one-half hour at 100° C. No circulation.

### THE DIELECTRIC STRENGTH OF MINERAL OIL IN RELATION TO ITS DISSOLVED GAS CONTENT.

Extensive work clearly indicates the importance of dissolved gases in the study of oiled solid insulation breakdown. In many cases, it appears that dielectric rupture under laboratory conditions is more a test of oil "gassing" than a study of fundamental insulation failure. It seems probable that most theories of oiled solid dielectric breakdown are fallacious largely because of the neglect of the "gassing" factor. This "gassing" may be due to gases dissolved in the oil or to the actual vaporization of the lighter oil fractions as the voltage is increased on the oil treated insulation. The data obtained suggest that the study of insulation failure must include consideration of those factors leading to gas or vapor formation in the dielectric.

### THE DIELECTRIC STRENGTH OF OIL AS A FUNCTION OF THE TYPE OF GAS DISSOLVED.

Should the dielectric strength of mineral oil be a function of the dissolved gas content, it is at once evident that the type of gas present must play a prominent rôle.

In Table II, three gases are investigated—air, hydrogen and carbon dioxide. At 25° C., with the rapidly applied voltage test, it will be noted that the oils, saturated with gas at atmospheric pressure, show dielectric strengths clearly dependent on the type of gas present and its sparking potential.

Table II also clearly indicates that the quantitative amount of dissolved gases at the saturation point is of no importance with the rapidly applied testing procedure. Carbon dioxide with its great solubility shows no greater gassing and subsequent lowering of dielectric strength than does hydrogen. The explanation is found in the fact that irrespective of the amounts of gases dissolved, all oils tested are gas saturated and hence necessarily have the same gassing tendency unless the test involves a change in oil temperature, a condition which was carefully avoided.

### THE EFFECT OF TESTING PROCEDURE ON DIELECTRIC STRENGTH.

It has already been indicated that gas solubility in mineral oil is not only a function of the type of gas but also of the testing temperature. With air it has been shown that increased temperature gives increased solubility. A similar effect is observed with hydrogen gas. In the case of carbon dioxide, however, the reverse is true. Tested at 25° C. and at 100° C., the following volume solubilities have been obtained in transformer oil:

| | | |
|---|---|---|
| Air..... | 10.8% at 25° C. | 12.7% at 100° C. |
| Hydrogen..... | 5.0% | 7.0% |
| Carbon Dioxide..... | 99.0% | 50.0% |

With long continued tests, giving rise to even slightly increased temperature of the oil, the gassing tendency of carbon dioxide treated oil is increased. This should result in a decreased dielectric strength. The reverse should be true with air or hydrogen saturated oil. Table IV gives the experimental results obtained using the minute test voltage

procedure. The relative change in the dielectric strength is in accord with the change in gas solubility, the carbon dioxide treated oil showing a marked drop when tested with slowly applied voltages.

### THE RELATION OF THE DIELECTRIC STRENGTH OF OIL TO THE ELECTRICAL CHARACTERISTICS OF THE DISSOLVED GAS.

In Table III, the dielectric strength of oil is calculated from the minimum sparking potential of the dissolved gas, using air saturated oil as a base. It is obvious that a linear relation could not be expected to be strictly true. For purpose of calculation, however, such a relation is assumed.

TABLE II.

*The Dielectric Strength of Transformer Oil as a Function of Its Gas Content at Atmospheric Pressure.*

| Gas Used to Saturate Oil. | Minimum Sparking Potential of Gas. | Volume Solubility (25° C.). | Temp. (° C.). | Average 60 Cycle Dielectric Strength of Oil Gas-Saturated at Atmospheric Pressure. | |
|---|---|---|---|---|---|
| | | | | Rapidly Applied Test. | Minute Test. |
| Air | 341 | 10.8% | 25 | 34.8 | 34.5 |
| Hydrogen | 302 | 5.0% | 25 | 31.8 | 32.4 |
| Carbon Dioxide | 419 | 99.0% | 25 | 36.1 | 31.2 |

TABLE III.

*Relation of Minimum Sparking Potential of Gas to Dielectric Strength of Oil Saturated with the Gas at Atmospheric Pressure.*

| Gas. | Minimum Sparking Potential. | Rapidly Applied Dielectric Strength of Gas-Saturated Oil at 25° C., Atmospheric Pressure. | |
|---|---|---|---|
| | | Predicted from Sparking Potential of Gas. | Experimental Result. |
| Carbon Dioxide | 419 | 42.8 | 36.1 |
| Air | 341 | — | 34.8 |
| Hydrogen | 302 | 30.8 | 31.8 |
| Helium | 261 | 26.6 | — |
| Nitrogen | 251 | 25.6 | — |

*Note:* In calculating the predicted oil strength, a linear relation between minimum spark potential of the gas and the oil breakdown is assumed, basing all calculations on the air-saturated oil value, experimentally determined.

The calculated results are of the general order of magnitude obtained experimentally.

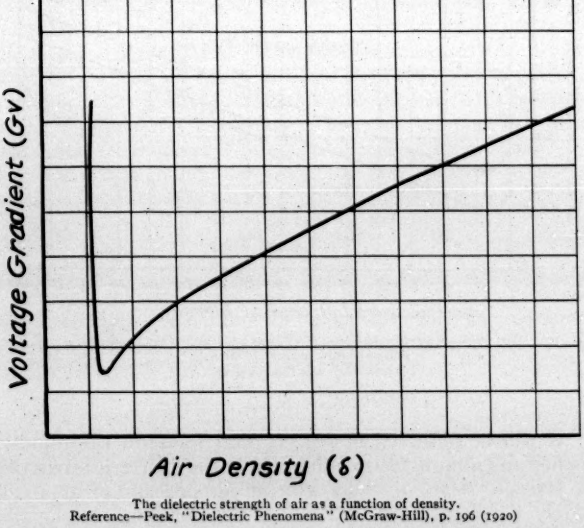
If the minimum gas sparking potential bears any relation to the dielectric strength of the gas saturated oil, the effect of nitrogen gas and helium gas should be even more pronounced. This is shown in Table III.

The effect of the type of gas on the dielectric strength of oil should be thoroughly investigated to determine whether the gas sparking potential is of major importance or whether the actual gas solubility characteristics are of predominating effect.

**The Effect of Decreased Gas Pressure on the Dielectric Strength of Air-Saturated Oil.**

It has been suggested that the dielectric strength of oil is dependent on a "gassing" phenomenon. This owes its source to oil-dissolved gas. The dielectric strength of the oil, there-

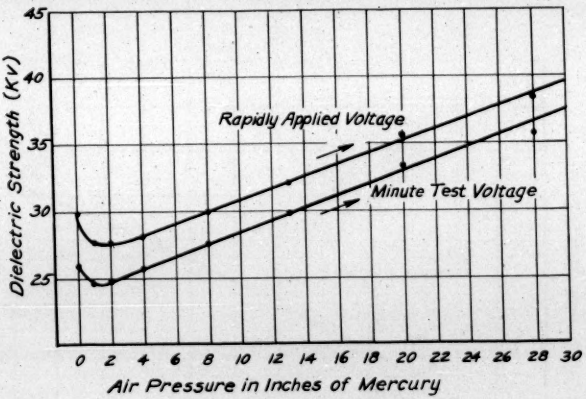
FIG. 10.




The dielectric strength of air as a function of density.
Reference—Peek, "Dielectric Phenomena" (McGraw-Hill), p. 196 (1920)

fore, should follow the dielectric strength of air as shown in Fig. 10. Figure 11 gives the average results of a number of runs made on transformer oil. In these studies, the difficulty of removing gas from oil by vacuum without mechanical agitation suggests that the most efficient method of test would be to eliminate the dissolved gas by spraying under vacuum at the start. Subsequent dielectric strength values were taken after the oil was allowed to stand under the selected vacuum for at least one hour. Only chemically dried air was used throughout such runs in order to avoid the effect of contaminating moisture. The atmospheric relative humidity was between 30 and 35 per cent. The temperature was room temperature which was taken at 25° C. ± 3° C. unless otherwise noted.

FIG. 11.




The dielectric strength of transformer oil as a function of the applied air pressure below 760 mm. of mercury
Gap setting—1/10″ (horizontal).
Electrodes—standard 1″ brass discs.
Temperature—25° C.

It will be observed in Fig. 11 that for both the rapidly applied and minute tests a minimum in the dielectric strength-air pressure relation occurs with an air pressure of approximately 1″ of mercury. Although the minimum in the di-

electric strength-pressure relation for air occurs at a lower pressure value, the similarity in the curves of Fig. 10 and Fig. 11 confirms the suggested importance of dissolved gases in the dielectric behavior of mineral oil. Further studies to locate more definitely the pressure corresponding to the minimum dielectric strength are described in subsequent paragraphs.

Whether the rapidly applied or minute test procedure be used, the dielectric strength of oil appears to be influenced fundamentally by a single factor although the final manifestation of this factor may be modified directly or indirectly by other effects. It is suggested that this fundamental factor is the dielectric strength of the gas itself. If such be the case, the effect of high gas pressures (above room pressure) can easily be predicted. The relations (1) and (2) should satisfactorily apply in predicting increased dielectric strength above room pressure.

A further prediction can also be made. Since the oil dielectric strength is fundamentally a function of the dielectric strength of the dissolved gas, the effect of high pressures should be similar to the effect on the gases themselves. Thus, starting with air at room pressure and temperature with a fixed gap, the dielectric strength varies directly with pressure in either direction. The relation, however, does not hold true indefinitely. E. Kern ((Sibley) *Journal of Engineering*, **18**, 391, 1904) has found that when the potential to sparkover between needle points with a .1″ to .3″ gap has increased with pressure to a value roughly ten times that needed under normal conditions, breakdown occurs at the same point irrespective of the pressure applied. This leads to the prediction that the breakdown of oil will increase with the gas pressure to a maximum value beyond which the dielectric strength-pressure relation will cease to apply, a prediction confirmed by the researches of F. Kock (5).

#### The Effect of High Gas Pressure Application.

It has been shown that the dielectric strength of mineral oil is a function of its dissolved gas content. The gas present under some conditions (long-time voltage application) may be effective only through its oil solubility change with tempera-

ture. Under other conditions (short-time voltage application) the gas may be effected through its minimum sparking voltage value as well as its changing solubility with temperature. In both cases, however (long and short-time voltage application), the effect of pressure below room pressure on the dielectric strength is a linear function. From the data obtained, the relation may be expressed as:

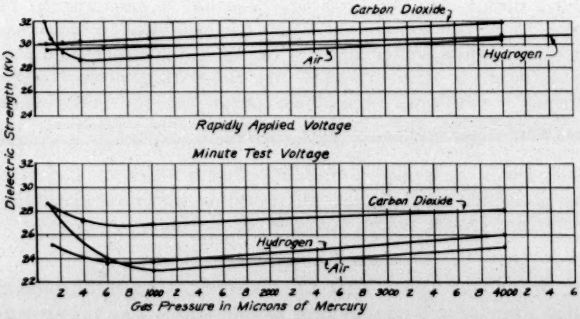
(1) Rapidly applied test $KV = .45P + 26.25$
(2) Minute test $KV = .45P + 23.25$

These mathematical expressions appy only for gas pressures above the pressure corresponding to the minimum dielectric strength value. The expressions are further limited by the fact that the quantities 26.25 of (1) and 23.25 (2) are directly dependent on the initial condition of the oil used.

**The Critical Pressure Value.**

Since the slope of the straight line expressing the relation between the pressure effect and the dielectric strength is the same for all gases above the "critical pressure" corresponding to the minimum dielectric strength value, data have been obtained giving further information concerning the "critical pressure" value for the gases, hydrogen, carbon dioxide and

FIG. 12.




The dependence of the "critical pressure" value of the dielectric strength of transformer oil on the type of test and the type of oil dissolved gas.
Gap—1/10" (horizontal).
Electrodes—1" brass discs.

air. In the previous discussion covering air only, it has been stated that the "critical pressure" corresponds approximately to 2 inches of mercury. Figure 12 shows the results obtained in the critical pressure range for both the rapidly applied and minute test procedure. As already anticipated, the "critical pressure" value is a function of the testing method. The results are summarized in Table IV.

TABLE IV.

*The Effect of the Testing Procedure and the Type of Gas Dissolved in Mineral Oil on the Gas Pressure Corresponding to Minimum Oil Breakdown.*

| Gas. | Pressure Corresponding to Minimum Oil Breakdown. Rapidly Applied Test. | Minute Test. |
|---|---|---|
| Air | 400 microns | 1000 microns |
| Carbon Dioxide | Less than 150 microns | 600 microns |
| Hydrogen | Less than 150 microns | 600 microns |

From such data it is concluded:

1. The "critical pressure" is a function of the testing procedure and the type of gas dissolved in the oil.

2. With rapidy applied voltages, the "critical pressure" is lower than with slowly applied voltages.

**The Effect of Applied Gas Pressure on the Dielectric Strength of Mineral Oil as a Function of Type of Gas.**

Extensive data covering the effect of gas pressure on the dielectric strength of oil for carbon dioxide, hydrogen and air at 25° C., minute and rapidly applied testing procedure, have been obtained. There has been demonstrated a linear relation between pressure and dielectric strength as already shown for air. For the sake of brevity, the data are not included in this article. In general, in the expression

$$KV = mP + n$$

the value of $m$ agrees well with that already given for air. Sufficient data are not available, however, to permit the conclusion that for all gases or even for air, the value of $m$ is always .45 as illustrated in previous paragraphs. Data are at hand, however, to show the linear decrease in oil dielectric strength as the pressure of the gas, either carbon dioxide, hydrogen or air, is decreased.

**Further Illustration of the Importance of Dissolved Gases in Determining the Dielectric Strength of Mineral Oil.**

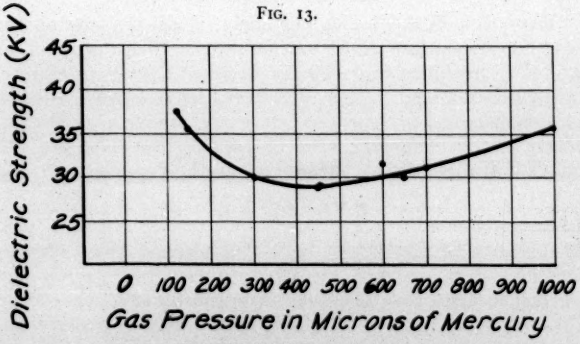
It may be objected that when a liquid is tested under reduced gas pressure, exceptional conditions are introduced which may alter or entirely change the normal breakdown characteristic. To circumvent this objection, the dielectric strength of oil as a function of gas content has been determined in the following manner:

1. The oil test cup is mounted in gas-tight vessel with collapsible sides whose movement will insure that the liquid within is at atmospheric pressure (hydrostatic).

2. The vessel is placed in a vacuum treating tank and completely filled with oil at the desired gas pressure. By slow filling, the oil dissolved gas will correspond to the applied pressure. The vessel is sealed after filling and is removed from the vacuum tank and tested at atmospheric pressure. The collapsible sides insure that the oil will be tested at atmospheric (hydrostatic) pressure with a gas content corresponding to the filling pressure selected.

The results of such tests confirm the part played by dissolved gases in determining the dielectric strength of oil. The results are shown in Fig. 13. It will be observed that

FIG. 13.




The dielectric strength of transformer oil as a function of its air content tested at (hydrostatic) atmospheric pressure.
Testing gap—1/10".
Electrodes—standard 1" brass discs.
Gap—horizontal.
Voltage—rapidly applied.

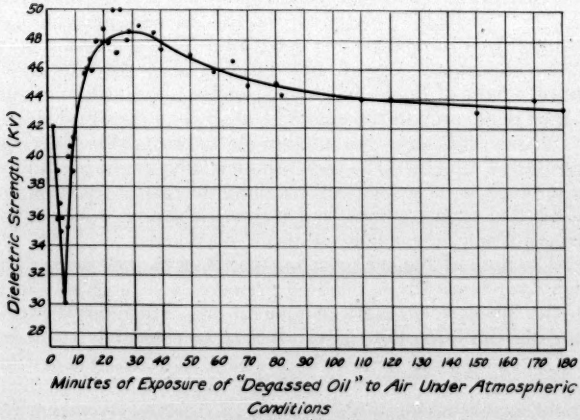
from these studies the pressure corresponding to the minimum dielectric strength is located at about 400 microns. This checks findings for gas pressure as distinct from hydrostatic pressure tests. These tests as noted in Fig. 13 were carried out with rapidly applied test voltage procedure. A gas pressure of 400 microns corresponds to an oil dissolved air content of approximately .0055 per cent. by volume at the testing temperature of 25° C. Since the oil under the conditions of the test is far from its air saturation value at atmospheric pressure when this minimum breakdown is reached, and since at lower and at higher air content the dielectric strength of the oil rises, it is clearly evident that a phenomenon similar to that controlling the dielectric strength of gases as a function of pressure is present. However, since the compressibility of oil may be neglected and since, even if important, its effect has been overcome in the hydrostatic experiment described, it is further to be concluded that the real dielectric strength of the oil has not been tested. Rather, it is concluded, the test has been entirely a test of the dissolved gas, or "gasifiable" materials in the oil and as such has followed well recognized gas behavior. This conclusion is of major importance since it follows necessarily that the theoretical study of liquid breakdown under alternating voltage can be made only in the complete absence of dissolved gases. It further indicates that studies to improve the dielectric strength of mineral oil as used commercially, might profitably be directed at those factors controlling the ease of gas elimination rather than confined to a theoretical study of molecular structure and other highly scientific phenomena.

The data of Fig. 13 must not be taken as indicative that high hydrostatically applied oil pressures will be of no effect on the dielectric strength of mineral oil. Secondary factors may play an important part. It is to be expected, however, that a completely de-gassed oil would show less change in dielectric strength with hydrostatically applied pressures than would an oil having a gas content at least great enough to correspond to the "critical" value (giving the minimum breakdown), an expectation which has been confirmed by Inge and Walther (1).

**The Effect of Air Re-Solution on the Dielectric Strength of De-Gassed Oil.**

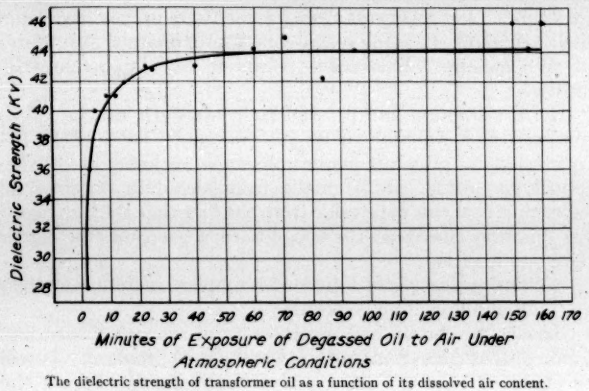
In previous paragraphs it has been shown that the dielectric strength of oil is a function of its gas content. Tests under reduced pressure as well as hydrostatic atmospheric tests on de-gassed and partially de-gassed oil have been cited. In the present illustration oil has been de-gassed at a pressure of 700 microns, at 1300 microns, and at 5000 microns. The oil has been exposed subsequently to its evacuation to air at atmospheric pressure. The dielectric strength tests as a function of time are used as a check to determine the effect of re-dissolved gas. It has been shown that the oil will absorb its full quantity of gas at a rapid rate. The rapidity of oil re-absorption by de-gassed oil in its effect on the dielectric strength is illustrated in Figs. 14, 15, and 16. In Fig. 14, de-gassed oil at 700 microns pressure shows a rapidly falling dielectric strength when exposed to conditions favoring the re-absorption of air. The drop shown is from a value of

FIG. 14.



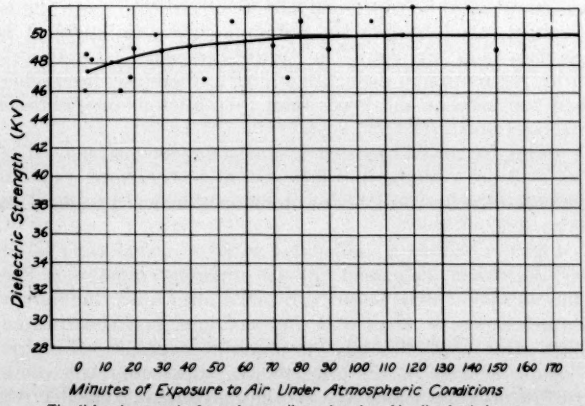

The dielectric strength of transformer oil as a function of its dissolved air content.
Gap—1/10" (horizontal).
Test electrodes—1" brass discs.
Test temperature—25° C.
Test voltage—rapidly applied.
Oil conditioning before run—degassed at 700 microns.
Mercury pressure—25° C.

FIG. 15.




The dielectric strength of transformer oil as a function of its dissolved air content.
Gap—1/10" (horizontal).
Test electrodes—1" brass electrodes.
Test temperature—25° C.
Test voltage—rapidly applied.
Oil conditioning—degassed at 1300 microns mercury pressure before test.

FIG. 16.




The dielectric strength of transformer oil as a function of its dissolved air content.
Gap—1/10" (horizontal).
Test electrodes—1" brass discs.
Test temperature—25° C.
Test voltage—rapidly applied.
Oil conditioning—degassed at 5000 microns mercury pressure before test.

42 kilovolts at 2 minutes to 30 kilovolts for 6 minutes of air exposure. A recovery in strength then sets in, the maximum dielectric strength being reached in approximately 25 minutes of air exposure. This curve points to two important conclusions:

1. A minimum in the dielectric strength of the oil is obtained as a function of its gas content. This checks the conclusions of previous paragraphs. No estimate of the dissolved gas value can be made from the data obtained in experiments of this type aside from the fact that the "critical" gas quantity dissolved corresponds to a gas pressure higher than 700 microns.

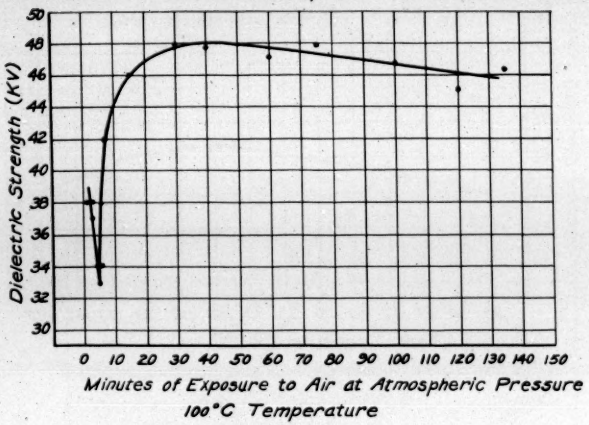
2. The rate of gas re-solution is complete in approximately 20 to 25 minutes of air exposure.

In Fig. 15 the oil has, at the start of the test illustrated, a gas content corresponding to 1300 microns pressure. It will be observed that the dielectric strength increases from the start of the experiment from a value of 28 kilovolts to a stable figure of about 44 kilovolts. In this test as in the former case, approximately 25 to 30 minutes are sufficient to saturate almost completely, the oil with air. From this illustrative test run it is to be concluded that the "critical" gas volume dissolved in oil to give the minimum dielectric strength is less than 1300 microns. The "critical pressure" corresponding to the minimum dielectric strength, therefore, lies higher than 700 microns and lower than 1300 microns on the basis of these tests.

In Fig. 16 the oil has been de-gassed at 5000 microns. The dissolved gas content is sufficiently high, therefore, that no evidence of a "critical" gas volume or "critical pressure" is obtainable.

Figure 17 shows a similar test made on transformer oil at 100° C. when de-gassed at 500 microns pressure. The minimum point determined is reached after approximately 5 minutes exposure to air and the maximum or gas saturated point after approximately 30 minutes exposure. Further evidence at 100° C. is thus shown, supporting the room temperature conclusions that (1) the gas content is an effective agent in determining the dielectric strength of oil, (2) the "critical" gas volume and "critical" gas pressure are higher

FIG. 17.



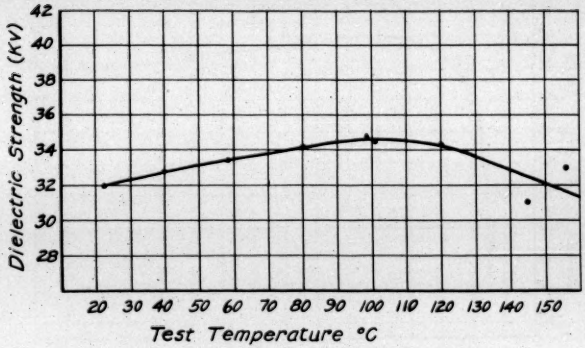

The dielectric strength of transformer oil as a function of its dissolved air content.
Gap—1/10" (horizontal).
Test electrodes—1" brass discs.
Test temperature—100° C.
Test voltage—rapidly applied.
Oil conditioning—degassed at 500 microns, 100° C. before test.

than 500 microns, and (3) that the rate of re-solution of air in de-aërated oil is rapid and practically complete in 25 to 30 minutes of air exposure under atmospheric conditions.

**The Effect of Temperature on the Dielectric Strength.**

It has been demonstrated that the ability of a gas to dissolve in oil is a function of temperature. Air solubility in transformer oil has been shown to increase approximately 13 per cent. between 25–100° C. This should have an effect on the dielectric strength of the oil. Figure 18 shows that the dielectric strength of transformer oil increases approximately 12 per cent. between 25 and 100° C. It may be admitted that this is not necessarily due to increased gas solubility in the oil as a result of increased temperature. The two phenomena may be entirely independent. However, from the data of Fig. 18, the linear relation between temperature and dielectric strength up to 100° C. is suggestive of a gas solution effect.

FIG. 18.




The effect of testing temperature on the dielectric strength of transformer oil.
Test gap—1/10" (horizontal).
Test electrodes—1" brass discs.
Test temperature—as shown.
Test voltage—rapidly applied.

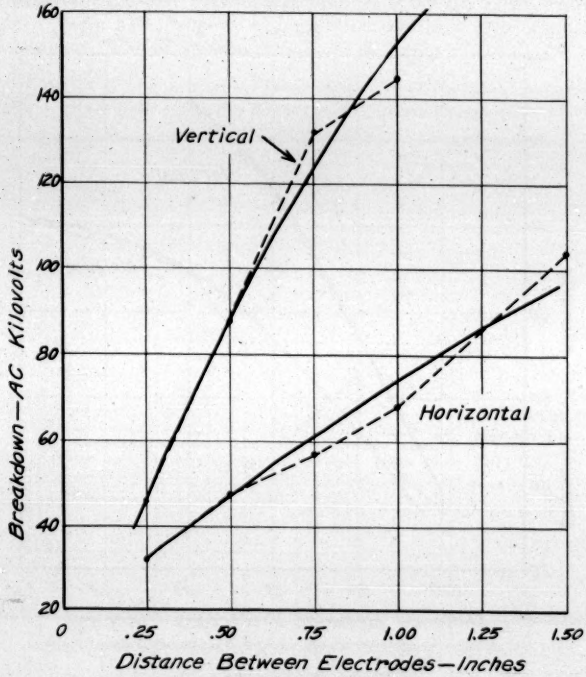
At sufficiently high temperature, oil vaporization under normal conditions would tend to lower the quantity of dissolved air by reducing its partial pressure which determines the amount of gas dissolved. This would lead to the prediction on the basis of "gas effect" that mineral oil at sufficiently high temperature would show a decreased dielectric strength. This is borne out in the data of Fig. 18.

**The Dielectric Strength of Oil as a Function of the Mechanical Set-Up.**

When a liquid is tested at its boiling point, the dielectric strength is lowered due to the formation of vaporized liquid (gas) in the dielectric field. The extent to which the dielectric strength is lowered depends on the mechanical arrangement and type of gap. With a gap so arranged as to allow free escape of the gas bubbles, the dielectric strength is not so greatly affected as when the escape of the gas is prevented. Such restriction can be obtained when parallel plane electrodes are held with their testing faces horizontal (gap is vertical). The rising gas bubbles then are held to the upper electrode and the dielectric strength of the boiling liquid under some conditions may be reduced to almost zero. With vertically

placed electrode faces (gap horizontal) the gas escapes with greater ease and the dielectric strength is maintained at considerably higher values than in the horizontal electrode set-up (gap vertical).

FIG. 19.

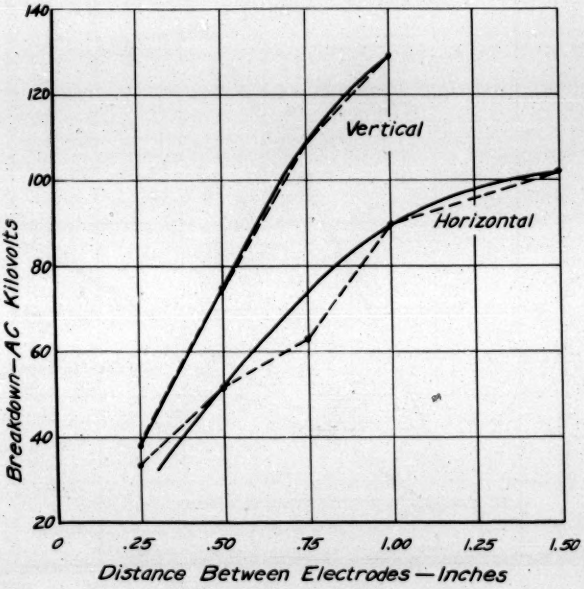



The A.C. thickness strength relation for transformer oil as affected by electrode position.
Electrodes—brass discs 10 ins. in diameter.
Test procedure—rapidly applied.
Gap setting—as shown.
Condition of oil between tests—well stirred.
(Points are average of 10 tests.)

The effect of dissolved gas on the dielectric strength of oil as already discussed in previous paragraphs presupposes the primary elimination of the gas bubble. From the behavior of a boiling liquid, it will be concluded that the dielectric

strength of oil would be dependent on the mechanical set-up of the testing electrodes. With horizontally placed electrodes (vertical gap), lower dielectric strength should result than with electrodes vertically placed (horizontal gap). With large plate electrodes the effect of position should be more pro-

FIG. 20.




The A.C. thickness strength relation for transformer oil as affected by electrode position.
Electrodes—brass discs 10″ in diam.
Test procedure—minute.
Gap setting—as shown.
Condition of oil between tests—well stirred.
(Points are average of five tests.)

nounced than with small plate electrodes, spheres or needle points. Such has been found true. The effect of position using 10″ brass parallel plate electrodes is illustrated in Figs. 19 and 20. It will be observed that whether minute or rapidly applied test procedure is used, the dielectric strength

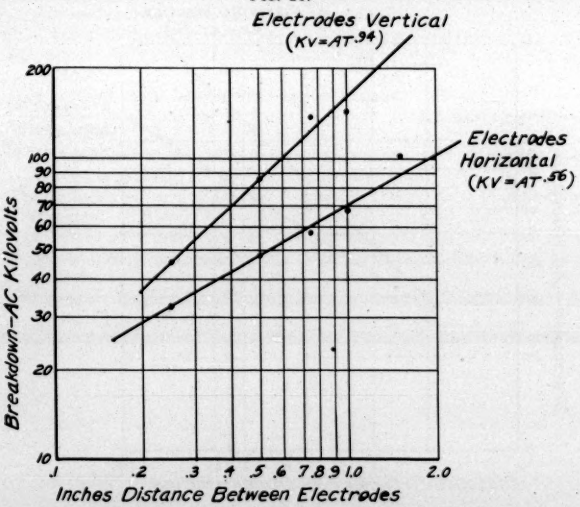
of oil is considerably lowered when the electrode faces are horizontal (gap vertical). The extent of the lowering of the dielectric strength is a function of the test gap and test procedure. With increased gap setting, the decrease in dielectric strength becomes pronounced. With rapidly applied tests the drop is greater than with slowly applied voltages. The effect is summarized in Table V.

TABLE V.

*The Effect of Electrode Position on the Dielectric Strength of Mineral Transformer Oil.*

| Gap Setting. | % Drop in Oil Strength Accompanying Change from Vertical Electrode (Gap Horizontal) to Horizontal Electrode Face (Gap Vertical) Position. Rapidly Applied Test. | Minute Test. |
|---|---|---|
| 1/4" | 29% | 10% |
| 1/2" | 44% | 31% |
| 1" | 52% | 31% |

FIG. 21.



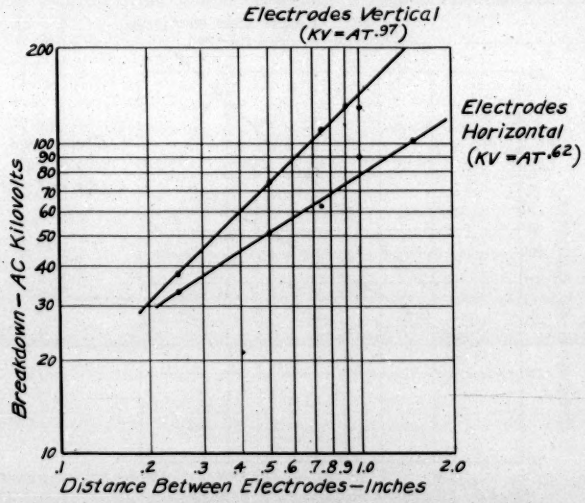

Logarithmic expression for the A.C. strength thickness relation in transformer oil.
Electrodes—10" brass discs.
Test procedure—rapidly applied.
Gap setting—as shown.
Condition of oil between tests—well stirred.
(Points are average of ten tests.)

Numerous investigators have attempted to determine the relation between gap distance and the dielectric strength of mineral oil. The relation is generally accepted as logarithmic:

$$KV = AD^n \ (D = \text{gap setting}).$$

The value of $n$, however, has not been determined with any degree of accuracy. Analysis of Figs. 19 and 20 shows that the gas content of the oil and its ease of liberation and escape from the dielectric field may be the fundamental cause of the lack of agreement. Figs. 19 and 20 show that $n$ is a distinct function of the testing set-up. The data of Figs. 19 and 20 are plotted in Figs. 21 and 22 as a logarithmic function. With vertical electrode faces (gap horizontal) the dielectric

FIG. 22.




The logarithmic expression of the A.C. strength thickness relation in transformer oil

Electrodes—brass discs 10" in diam.
Test procedure—minute.
Gap setting—as shown.
Condition of oil between tests—well stirred.
(Points are average of five tests.)

strength involves a minimum of secondary effect involving gas freedom of escape. Under such conditions $n$ approximates unity irrespective of the method of voltage application. With horizontally placed electrodes (gap vertical), however, $n$ is not unity but approaches the two-third or one-half value. With such effects it appears impossible to assign a definite value to the exponent $n$, involving as it does those miscellaneous factors which determine the ease of gas formation and escape and the effect of voltage on the trapped gas, factors which can hardly be accurately controlled.

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Above 20 atmospheres, the dielectric strength of liquids rises more slowly with pressure increase and reaches a value characteristic of each material.
6. The Relation Between Gas Solubility and Temperature. G. Tamman. *Z. Anorg. Chem.*, 158, 17, 1926.

**An Extraordinary Photoelectric Cell.**—A well-known company, maker of precision electrical measuring instruments, recently has developed a photo-electric cell that is radical both in type and design. The cell is electronic in character yet does not need to operate in vacuum, gas or liquid. The cell contains a highly sensitive light disc which transforms light energy directly into electrical energy without the use of any auxiliary voltage whatsoever. The cell delivers about 1.4 microamperes per foot-candle of light intensity or 120 micro-amperes per lumen. For low external resistance in the cell circuit the variation in current with light intensity is practically a straightline relationship. The cell is not subject to physical or chemical change, can be exposed to direct sunlight without deterioration, has no dark current and is non-microphonic. Due to simplicity of construction, this cell of unlimited life, high sensitivity and high current output can be produced at relatively low cost.

C.

**Tidsskrift for Kjemi og Bergvesen.**—The Journal of the Franklin Institute is the recipient of a special number of the *Journal of Chemistry and Mining*. Anyone caring to look over this interesting issue should be warned that it is printed in the native language, Norwegian. This special number celebrates the 175th year of Norwegian Mining Education and contains a collection of interesting papers, historical in nature, dealing with educational development and the growth of the coal, ore and rock mining industries.

C.

# MOBILITIES OF GASEOUS IONS IN $CH_3NO_2$-$H_2$ AND $CH_3CN$-$H_2$ MIXTURES.

BY

ELIZABETH ANN HIGLEY AND CAROLYN C. THORSEN.

ABSTRACT.

Extending previous investigations by Loeb of mobilities in gaseous mixtures using his procedure except that the auxiliary field in these measurements was made equal to the advancing field thus giving absolute values of the mobilities, measurements of mobilities were made in mixtures of $CH_3NO_2$-$H_2$ and $CH_3CN$-$H_2$. The mobilities in $H_2$ were 7.12 for the positive ions and 10.46 for the negative ions in cm./sec. per volt/cm. Those in $CH_3NO_2$ were 0.221 cm./sec. per volt/cm. for both ions and in $CH_3CN$ they were 0.234 cm./sec. per volt/cm. for both ions. Both ion mobilities deviated from Blanc's law in $CH_3NO_2$ indicating the formation of complexes with the $CH_3NO_2$ ions somewhat greater in size than the normal ions in $H_2$. The molecules attached to negative ions somewhat less readily than to the positive ions but both final ions were of the same size. In $CH_3CN$ mixtures both positive and negative ions deviated from Blanc's law, the positive ion showing more ready attachment of $CH_3CN$. The negative ion had consistently a higher mobility than the positive ion, a circumstance indicating a smaller ion and suggesting that the attaching molecule might not be $CH_3CN$ but some impurity. Both ion addition products in $CH_3CN$ are larger than the normal ion in $H_2$ but smaller than those in $CH_3NO_2$ as was to be expected.

The studies of mobilities in gaseous mixtures by Loeb[1,2,3,4,5] and by Tyndall and Grindley[6] have shown that interesting information can be gained concerning the interaction of electrical charges with different molecular species. The recent investigations of molecular shape and structure following from the studies of dielectric constants and the Kerr coefficients by Debye,[7] Smyth,[8] H. A. Stuart[9] and others have led to the

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[7] Debye, Polar Molecules.
[8] Smyth, C. P., Dielectric Constant and Molecular Structure.
[9] Stuart, H. A., *Zeits. f. Phys.*, **59**, 13 (1929) and **63**, 533 (1930).

hope that possible correlations between these structures and the charge affinity of the molecules, and hence molecular attachment for the ions, might result from further investigations of certain mixtures. The formation of attachment products is quite definitely indicated in such mobility measurements in mixtures by an initial change of one or both ion mobilities on addition of traces of the gas to be studied. These changes in mobilities cause marked deviations from Blanc's law for mobilities in mixtures. In its simplest form Blanc's law is expressed in terms of the reciprocal of the mobility (the resistance to the motion of the ion). If, then, the structure of the ion is not changed by mixing, the law is given by

$$R_{ab} = fR_a + (1 - f)R_b,$$

$f$ being the mole fraction (i.e. partial pressure of the gas in a binary mixture) and $R_a = 1/k_a$ and $R_b = 1/k_b$, the resistances to the ions characteristic of gases $a$ and $b$ alone, and $R_{ab}$ the resistance offered by the mixture. $k_a$ and $k_b$ are the mobilities in the gases $a$ and $b$. It is seen that $R_{ab}$ is a linear function of the composition of the gas. Any marked departure from linearity in the $R_{ab} - f$ curves indicates a change in the ion. A strong attraction between ions and molecules and a reconstitution of the ion due to the selective attraction of one gaseous component to the charge will make itself noticed by a marked departure from the law for very small additions of that component.

Certain probable structural peculiarities of the nitro bodies and of the cyanide group suggested in conference by H. A. Stuart together with incidental observations by Loeb in the course of other investigations made it seem of importance to investigate these substances. In addition E. O. Hulbert had requested information concerning the action of the nitro bodies on the ions in respect to the condition of electrical carriers in the upper atmosphere. Because of the unstable and poisonous nature of $N_2O_4$, and the difficulty of working with $HNO_3$, and because of the poisonous character of HCN it was thought that investigations of the simplest organic derivatives containing these groups might be of value. For this purpose $CH_3NO_2$ and $CH_3CN$ were studied. Further studies of $CH_3NC$, the isocyanide, are envisaged at a later

date. Structurally the simple organic derivatives should yield the same results as the inorganic substances.

Owing to the impossibility of obtaining pure organic substances for investigations and owing to the effect of traces of impurity on the ions it was suspected that some complications in the results might be introduced from this cause. This appears to have occurred in the case of negative ions in $CH_3CN$. The presence of this complication is clearly indicated where it occurs and the results obtained merit presentation as they add information concerning mobilities in gases previously not studied.

## EXPERIMENTAL PROCEDURE.

The measurements were made with the Franck modification of the Rutherford A. C. method for mobility measurement employing the apparatus and method used by Loeb[1,3,4] in his earlier work on mixtures. The constant auxiliary field used in other measurements was replaced by a variable field. This field was kept approximately equal to the advancing potential of the alternating field. The effect of interpenetration of fields was thus minimized, giving as a result very consistent electrometer deflections and sharp intercepts in the mobility curves. The values obtained in this way should represent absolute values on the new mobility scale.

Tank hydrogen was used in all measurements, being introduced into the chamber through a series of meter-long drying tubes: one of NaOH, one of $CaCl_2$, and two of $P_2O_5$. From the drying train the gas passed through a double trap cooled to liquid air temperature. Both the $CH_3CN$ and $CH_3NO_2$ were obtained from the chemistry department laboratory stock. The first was an Eastman Kodak Co. product (technically pure) and the second came from C. A. F. Kahlbaum. The procedure in using both liquids was the same. The substance was placed in a clean flask and attached to the apparatus. From there a portion was distilled in vacuum into a trap and frozen with liquid air. The system was then evacuated, and the material fractionated into a second trap from which it was distilled into the ionization chamber as needed, only central fractions being used.

EXPERIMENTAL RESULTS.

Measurements were first made in pure $H_2$ at 70 cm. pressure. The results obtained were 7.75 and 7.7 cm./sec. per volt/cm. for positive ions, and 13.05 and 10.08 cm./sec. per volt/cm. for negative ions. Next a measurement was made on $H_2$ contaminated with a trace of nitro methane. After this the system was thoroughly evacuated, rinsed with hydrogen, and further measurements taken in pure $H_2$. It was found that the values for the positive mobilities were slightly lower than those made in the uncontaminated chamber. The negative mobilities returned to normal values. Some difficulty was found, however, in determining the negative mobilities because of the presence of free electrons.

After measurements in $CH_3NO_2$ were completed the system was again evacuated and measurements made in pure $H_2$. At this time normal values for both positive and negative ions were obtained. The later values of the mobilities obtained in $H_2$ are as follows (at 70 cm. pressure):

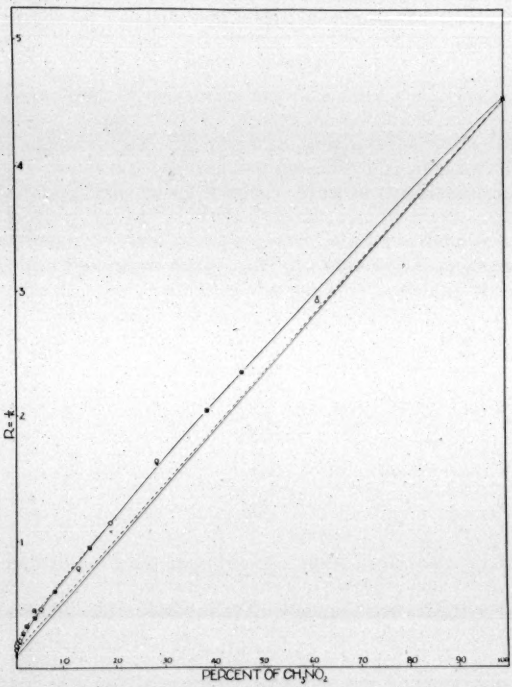
| Positive ions. | Negative ions. |
|---|---|
| 7.15 | 26.3 |
| 7.00 | 19.4 |
| 7.07 | 10.45 |
| 7.14 | 20.3 |
| 6.98 | 11.5 |
| 8.07 | 10.02 |
| 8.09 | 10.65 |

In view of these results the positive mobilities obtained before contamination were used as a basis of computation, the average value being 7.73 cm./sec. per volt/cm. Rejecting the values of the negative mobilities from measurements which showed the presence of free electrons, the average negative mobility obtained was 11.38 cm./sec. per volt/cm. When reduced to atmospheric pressure these values become 7.12 cm./sec. per volt/cm. for positive ions and 10.46 cm./sec. per volt/cm. for negative ions.

The measurement of the mobilities in $CH_3NO_2$ was relatively simple. Difficulty was encountered, however, in measuring mobilities at low pressures because the gas condensed under compression in the McLeod gage. This condensation prevented the use of pressures from 100 microns to one mm., which could be read on the mercury manometer.

The mobility of pure $CH_3NO_2$ was measured at a pressure of 35 mm. which was approximately its vapor pressure at room temperature. The values of the mobility constant were the

FIG. 1.



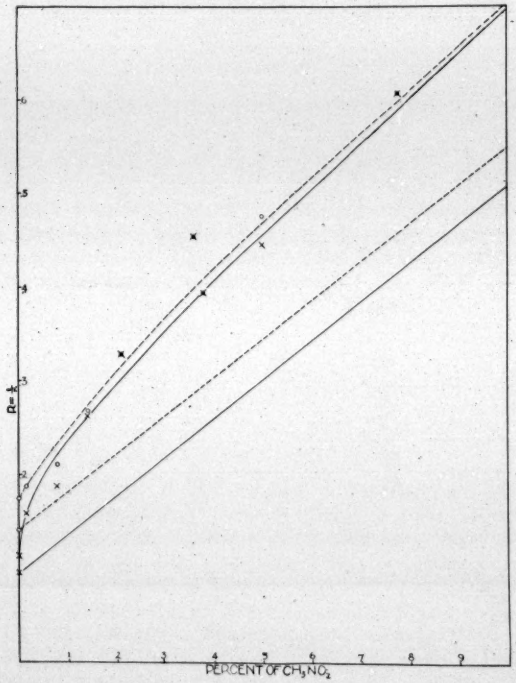

same for both positive and negative ions within the limits of uncertainty. The results were:

| P. | + ions. | − ions. |
|---|---|---|
| 35 mm. | 0.217 | 0.217 |
| 33 | 0.224 | 0.224 |

The average value for both + and − ion mobilities to be used as a basis for computation is 0.221 cm./sec. per volt/cm.

Measurements were then made in mixtures of $CH_3NO_2$ and $H_2$. In mixtures containing as little as 5 per cent. $CH_3NO_2$ the total pressure used was 70 cm. Greater percentages could only be studied by using lower total pressures.

FIG. 2.




The values thus obtained were then reduced to atmospheric pressure. It was found inconvenient to continue measurements at these low pressures above 70 per cent. Curves representing the results of the work done in mixtures of nitro methane and hydrogen are shown in Figs. 1 and 2, the circles

representing positive ions and the crosses negative ions. The reciprocal mobilities are plotted as ordinates and the fractions of nitro methane as abscissæ. The curve deviates throughout from that to be expected from Blanc's law. A sharp initial decrease in mobility is seen in the first 5 per cent. of the curve. The curves for positive and negative values are nearly coincident.

METHYL CYANIDE.

The problem of measuring mobilities in $CH_3CN$ was complicated by the fact that the gas condensed slowly on the walls of the chamber and the pressure thus gradually decreased. This was not at first realized and probably accounts for the inconsistency of the earlier results. Most of the measurements were taken at a pressure of about 6 cm., two that were taken at lower pressure—3 cm. and 4 cm.—did not have definite break points and the values of the mobility obtained from them are questionable. The values of the mobility constant obtained are:

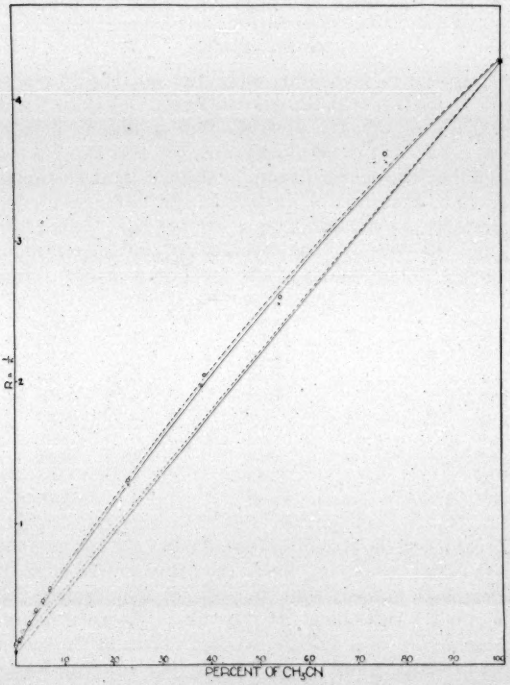
| Pressure in mm. | Positive ions. | Negative ions. |
|---|---|---|
| 69 | 0.249 | 0.223 |
| 76 | 0.227 | 0.242 |
| 69 | 0.226 | 0.240 |
| 40 | 0.279 | 0.311 |
| 58 | 0.243 | 0.224 |
| 27 | 0.192 | 0.262 |
| 57 | 0.238 | 0.241 |
| 50 | 0.223 | 0.231 |

The values of the mobilities obtained in the last two measurements under conditions where the pressure was more carefully controlled, indicate that the positive and negative values are very nearly the same. If the values observed below 50 mm. pressure are rejected the average values of the mobility constant in $CH_3CN$ are 0.234 cm./sec. per volt/cm. for both positive and negative ions.

Mixture work in $CH_3CN$ and $H_2$ was next undertaken. As in the case of $CH_3NO_2$ it was found impossible to cover the entire percentage range at 70 cm. pressure. Low pressures were used in mixtures containing more than 10 per cent. $CH_3CN$.

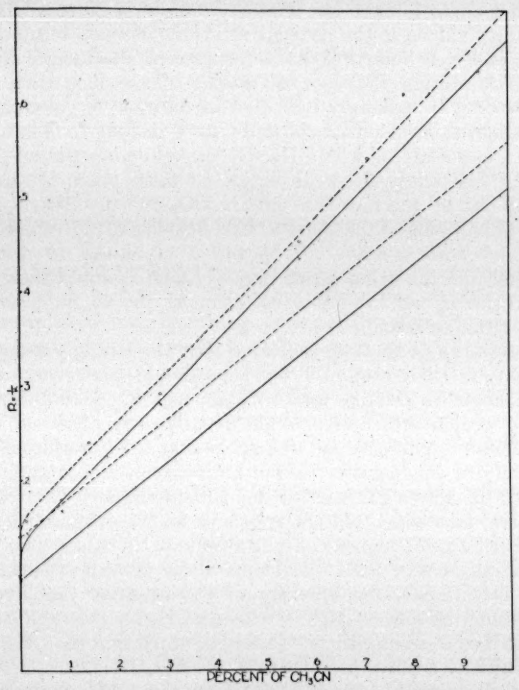
Curves for this work are shown in Figs. 3 and 4, reciprocal mobilities being plotted as ordinates against fractions of $CH_3CN$ as abscissæ. The circles represent positive ions and

FIG. 3.




the crosses negative ions. The mobilities again fall below those to be expected from the Blanc's law relation. The values of mobilities for negative ions are consistently higher (reciprocal mobilities lower) than those of the positive ions.

FIG. 4.




## CONCLUSIONS.

The results in both $CH_3NO_2$ and $CH_3CN$ appear to indicate attachment of these molecules to both positive and negative ions. It is next to be observed that the effect of the minutest traces of these molecules is not as great as that for traces of many other molecules on the ions. Thus 20 microns of $CH_3CN$ reduced the positive mobility quite definitely, but the value for the negative ion was only slightly lowered, indicating that the number of impacts of the negative ion with $CH_3CN$ during the time taken to cross the distance between the plates

sufficed only to cause a few of the ions to be reconstituted. Such a change in the ion produces a gradual decrease in the mobility values as the reconstituted ions increase in number. This is a well known effect in the case of all changes of ion mobility during the time of transit of the ions with this method; it is strikingly indicated in the case of electron attachment to form ions as shown by Loeb in 1921.[10] The same is in a measure true with $CH_3NO_2$ for 20 microns partial pressure. The relatively weak action of these gases is further borne out by the fact that in $CH_3NO_2$ and in $CH_3CN$ prolonged pumping of the chamber and flushing with fresh $H_2$ gas restored both positive and negative mobilities to normal values. In the other gases like $NH_3$, HCl, and Ether this could not be achieved short of cleaning the whole chamber with cleaning mixture.

Stewart's predictions indicated that the strongly negative polarity of the $NO_2$ and CN groups should selectively cause attachment to positive ions. Taken together with the relatively weaker attachment of the negative ions observed, this prediction might lead one to suspect that the lowering of the mobility of the negative ions in both cases was not an effect due to the active gas but was due to some impurity active on negative ions which did not appear in sufficient quantities to be noticed until higher concentrations of the gases $CH_3NO_2$ and $CH_3CN$ were used. Evidence to be presented indicates that in $CH_3NO_2$ the lowering of the negative mobility is definitely due to the $CH_3NO_2$ while in $CH_3CN$ the result may be ascribed to an impurity. It may be noted that the $CH_3NO_2$ was initially a purer product than the $CH_3CN$.

In the work of Loeb and Dyk [4] in mixtures of $H_2$ and amines it was noted that while $NH_3$ materially increased the positive mobility (reduced $R$) in $CH_3NH_2$ the mobility was unchanged and in $CH_3CH_2CH_2NH_2$ it was markedly decreased ($R$ increased). The fact that the $NH_3$ group selectively adds to the positive ion both in the case of $NH_3$ and $CH_3CH_2CH_2NH_2$ (as shown by an abrupt change in mobility on mixing with neutral gases) makes it probable that $CH_3NH_2$ must also add to the positive ion. The absence of any change in $k_+$ as a

[10] Loeb, L. B., *Phys. Rev.*, 17, 89 (1921).

result of mixing then indicates that the group replaced by $CH_3NH_2$ is about of the same size as the group forming the normal positive ion in $H_2$.

In the present case the change in the value of the positive ion mobility in $H_2$ by addition of $CH_3NO_2$ alters the initial value of $k$ from 7.1 to 5.7 for 20 microns partial pressure, and the negative value from 10.4 to 8.75. Both ions reach approximately the same value of $k$ for $f = 0.014$ or 10 mm. pressure. Now in pure $CH_3NO_2$ ($f = 1.0$) the mobilities for positive and negative ions are the same. Thus the Blanc law lines slowly converge towards the common value at $f = 1.0$. In the mixture at $f = 0.014$ the mutual convergence of the two values of $k$ by Blanc's law is negligible while the observed values of $k_+$ and $k_-$ at this concentration are sensibly equal. This can mean only one thing; both positive ions and negative ions form addition products of the same size with $CH_3NO_2$. The replacement of the foreign molecule constituting the normal positive ion in $H_2$ by $CH_3NO_2$ thus proceeds with greater speed than on the negative ion, both ions, however, eventually forming the same sized ion complex. In $CH_3CN$ the process is somewhat different. The $CH_3CN$ adds quite readily to the positive ion. It shows considerable reluctance to add to the negative ion. Furthermore the negative ion is consistently higher in mobility ($R$ lower) than the positive ion up to mixture very rich in $CH_3CN$ where differences in mobility are not easily detected. This indicates that while, with the particular sample of $CH_3CN$ used, both ions ultimately form addition replacement products, the positive ion reacts more strongly with the gas than the negative and then forms a product of larger size (smaller $k$), which is consistently indicated up to a mixture which is nearly all $CH_3CN$. This could signify that the positive ion adds $CH_3CN$ while the negative ion attracts some accompanying impurity. As the mobilities of the addition products on positive ions and negative ions in mixtures rich in $CH_3CN$ do not differ radically the apparently common value in pure $CH_3CN$ masks the small difference due to this other addition product. The masking of mobility differences in high concentrations of $CH_3CN$ is due to the greater importance of dielectric constant which influences the mobility without changing the ion.

From the values of $k$ in dilute mixtures of $CH_3NO_2$ and $CH_3CN$ in $H_2$ where the differences in the dielectric constants of the mixtures are not great it can be seen that the complex formed with the $CH_3NO_2$ is slightly bulkier than that formed with $CH_3CN$.

We may thus conclude that in $H_2$, $CH_3NO_2$ attaches to form stable complexes with positive ions, and also attaches to form complexes with negative ions but less avidly; while $CH_3CN$ forms complexes with positive ions fairly readily but the formation of a complex with the negative ion is doubtful. An attachment product on the negative ions in these experiments may tentatively be ascribed to some other impurity present in the $CH_3CN$. Furthermore the addition products of $CH_3NO_2$ with the positive and negative ions are of the same size and larger than the corresponding products in $CH_3CN$. In both cases the ions are larger than those normally produced by positive and negative carriers in hydrogen.

It may be added that results of mixture studies where air is used as the neutral gas instead of hydrogen have been shown by Loeb[1, 2, 3, 5] to be closely parallel to those in hydrogen. Hydrogen is used because the high mobilities in hydrogen enable clear differentiation to be made in the case of small changes in mobility produced by addition products. Air giving lower normal mobilities does not permit such a large range of variation of mobilities in mixtures and thus makes accurate studies more difficult. The results of these studies in $H_2$ can therefore be assumed to be equally applicable to mixtures of these substances with air as regards general behavior.

In conclusion the writers wish to express their sincere thanks to Professor Leonard B. Loeb at whose suggestion and under whose direction this work was undertaken.

# PHOTOMETRIC DETERMINATION OF CAMERA EXPOSURES FOR MOTION PICTURE WORK.

BY

ALAN M. GUNDELFINGER AND JEROME W. STAFFORD.

ABSTRACT.

A photometric method for the determination of camera exposures in motion picture work is described. The relation of exposure, object brightness and lens stop number is derived, and the proportionality constant empirically determined for "Pan Astro" lenses of two- and three-inch focal length. A nomographic chart of the exposure relation is given to simplify the determination of the lens stop number to be used for a given object brightness.

## INTRODUCTION.

At the present time practically all camera exposures in motion picture work are determined by the judgment of the cameraman. If by the use of a reliable photometer this personal element could be eliminated, many advantages would ensue, the most obvious being greater uniformity in negatives, with the resultant reduced laboratory costs in processing. The following investigation was carried out with the idea of increasing the uniformity of Multicolor negatives, more with the intention of increasing the efficiency of the laboratory than as an aid in the actual photographing. Although the method worked out was for color negatives of the bipack type, it is equally applicable to black and white or other photographic processes.

It might not be amiss to state here that there is no intention of detracting from the ability of the cinematographer or of making him a mere machine. On the contrary, a photometric method of determining exposures should be very useful to him in achieving the particular effect desired. As a photometer, the human eye is far from precise. If the exposure value is to be determined by judgment, an error of two or three times the best value might easily be introduced. Due to the great latitude of negative emulsions now in use, this error may not mean an unusable negative but it will certainly require special treatment in the laboratory if a satisfactory

print is to be obtained. The use of a photometer should be of particular advantage in the case of special effects and trick shots.

THEORETICAL CONSIDERATIONS.

The ultimate aim in motion picture work, whether in color or in black and white, is to obtain a print which, when exhibited in the theater, will be pleasing to the average person. One of the major requirements is that relative light intensities from objects being photographed should be reproduced as they normally are. This involves the sensitometry of tone reproduction which is beyond the scope of this paper. However, one of the necessary conditions of true tone reproduction is that the negative exposures shall fall on the straight-line portion of the H. and D. curve. The problem at hand is the fulfillment of this condition by the use of a photometric method.

The average intensity range is probably not over a hundred to one, and in many cases much less than that. The term *subject contrast* is commonly used to designate the intensity range of the scene being photographed, and will be thus used here. A subject contrast of a hundred to one will be assumed to be a desirable range to cover. This, of course, corresponds to a log $E$ value of 2.0. The average negative emulsion at gammas ordinarily used has a straight-line portion, the projection of which on the log $E$ axis is nearer 3.0 than 2.0. In the case of bipack film the latitude, i.e., the projection of the straight-line portion of the H. and D. curve on the log $E$ axis, is in the neighborhood of 2.5. In this case there are two H. and D. curves to be considered and it is the common log $E$ projection of the two straight lines that determines the latitude. If the subject contrast is in log terms 2.0 and the negative is capable of handling 2.5, the difference is 0.5, or, in other words, three times the exposure that would just keep off the toe of the curve would still be on the usable range but just below the shoulder. Two negatives exposed in this manner would give identical prints provided correct printing exposures were used.

Let us assume that a gray object with a reflection factor of 50 per cent. is to be photographed and further that the brightness of the object is known. What exposure should be

used in order to obtain a negative with this 50 per cent. reflecting object in the best average position on the H. and D. curve? Exposure is here defined by the product of the intensity of illumination on the film times the time. Meter candles will be used as the unit of intensity and seconds as the time unit. The unit of exposure is then meter-candle-seconds, abbreviated M.C.S. The mid-point of the straight-line portion is determined from the characteristic curve of the negative material. If a subject contrast of a hundred is to be used, objects with 10 per cent. reflection factors should fall at this point. The 50 per cent. reflecting object should then be at the point on the curve with an abscissa 0.7 greater than the mid-point. By determining the antilogarithm of this abscissa the required exposure of the 50 per cent. reflecting object is obtained.

The desired exposure on the film for the 50 per cent. reflecting object having been determined, it is now necessary to determine how to obtain that exposure, the brightness of the object being known, of course. The intensity of illumination on the film will be proportional to the brightness of the object and the effective area of the lens, and inversely proportional to the distance squared and the lateral magnification squared. Written in equation form this becomes:

$$(1) \qquad I = \frac{B \times A}{(D \times M)^2} C,$$

where $B$ = Brightness of the object in apparent foot-candles,
$A$ = Effective area of the lens,
$D$ = Distance of the object from the lens,
$M$ = Lateral magnification,
$C$ = Proportionality constant.

But from geometrical optics, the lateral magnification equals the ratio of the first focal distance divided by the distance from the object to the first focal point. Although not strictly rigorous, the distance $D$ above will be assumed to be the distance from the object to the first focal point. If $f$ designates the focal length of the lens, the relation $M = \frac{f}{D}$ follows.

Substituting for $M$ in equation (1)

$$I = \frac{B \times A}{f^2} C. \tag{2}$$

Introducing $s$ as the stop number of the lens or aperture ratio, as it is often called, the following relation holds:

$$\frac{d}{f} = \frac{1}{s} \quad \text{or} \quad d = \frac{f}{s},$$

where $d$ is the effective lens diameter. If now the effective area of the lens is expressed in terms of the stop number and the focal length of the lens, equation (3) follows:

$$A = \frac{\pi d^2}{4} = \frac{\pi f^2}{4s^2}. \tag{3}$$

Now, by combining (2) and (3), the expression for the intensity in terms of the brightness of the object and the stop number used results,

$$I = \frac{\pi B}{4s^2} C.$$

Since $E$, the exposure, equals intensity times time, the final relation is obvious:

$$E = \frac{t \times \pi \times B}{4s^2} C.$$

The constant $C$ depends primarily upon the type of photographic objective, its transmission, internal reflections, etc. The experimental part of this investigation is the empirical determination of this proportionality constant.

It should be pointed out that for this work the reciprocity law has been assumed to hold. Although this is not strictly the case, as is well known, assuming its validity does not introduce any serious error. The orders of magnitude of intensities and times are the same throughout although the sensitometer used was of the time-scale type, while camera exposures are of the nature of an intensity scale. This difference, however, is negligible inasmuch as the sensitometer is used only as a relative standard.

### EVALUATION OF "C."

All sensitometer exposures were made on an Eastman sensitometer of the time-scale type using as a light source a standard acetylene burner. The light was filtered to daylight quality with a Wratten 79 filter. All exposures were made with this quality as the starting point. In the cases where filters were used they were added to the 79 filter. Standard DuPont Dupack negative stock was used throughout. The bipack exposures were made as follows. The two negatives were placed with their emulsions together in the sensitometer with the orthochromatic negative towards the light source. The light path was from the standard lamp to the base side of the orthochromatic, through the base, emulsion and red filter of the orthochromatic, and then to the emulsion of the panchromatic. The sensitometer used compares very closely with the new Type IIb Eastman sensitometer.

Intensity measurements were made with a Leeds and Northrup Macbeth illuminometer. All densities were measured with a Capstaff densitometer. Both a Bell and Howell and a Mitchell standard motion picture camera adapted to the bipack system were used. In all cases a Mitchell motor was used to run the camera at the constant speed of 24 frames per second.

When filters were used they were selected from the Wratten gelatin series cemented in *B* glass.

As a test object, a gray chart was used that had six shades or densities on it. Each shade was a uniformly flashed matte photographic paper developed to the desired density. The various densities of the chart were determined with a Macbeth illuminometer. The standard lamp was placed on the paper and the illumination measured. Knowing the incident light and measuring the reflected light gave data from which the density of the paper could be computed. By density is meant the logarithm of the ratio of the incident light to the reflected light. The six densities were .06, .33, .54, .82, .96 and 1.18. Thus the test object corresponds to a subject contrast of one to thirteen.

In order to evaluate the constant of the formula, photographic camera tests were made of the gray chart. In all

cases intensity measurements were made on the chart before photographing. As a starting point the chart was set up in sunlight and photographed with a Bell and Howell camera at a film speed of 24 frames per second and an angular shutter opening of 170 degrees. The stop number was set at an arbitrary point judged to place the exposures from the chart approximately on the straight-line portion of the H. and D. curve. Camera exposures were made without a filter as well as with filter 86-A, 86 and K-2. These tests were developed for the same time in the negative machine. At the end of each test there was spliced a sensitometer exposure made with the corresponding filter of the test and from the same roll of raw stock. After development, densities of the various tests were determined and curves plotted. In the case of the sensitometer exposures the standard H. and D. curves were plotted. In the case of the exposures on the chart the density from the negative was plotted against the corresponding gray density of the paper. In the second case the slope of the straight line is the actual negative gamma. Although the points did not fall on as straight a line as in the case of the sensitometer exposures, by assuming a straight line and fitting it to the actual points in the best manner possible, slopes were obtained that corresponded remarkably well with the sensitometer curves. With data now available it was possible to substitute in the exposure formula and determine the constant "*C*." The density produced on the test negative from the measured area on the chart was noted. The antilogarithm of the log *E* value from the H. and D. curve corresponding to this density was then substituted for *E* in the exposure formula. The brightness *B* was the measured intensity of the chart; the stop number was read from the lens, and the time was computed from the camera speed, which was 0.02 second for a 170 degree shutter and a film speed of 90 feet per minute.

The following tabulation shows the results of the various camera tests. The values in the column "Actual Log *E*" were obtained by measuring the test negative density within the area where intensity was determined during exposure, and noting the log *E* value for this density from the corresponding H. and D. curve. The antilogarithm of this value was sub-

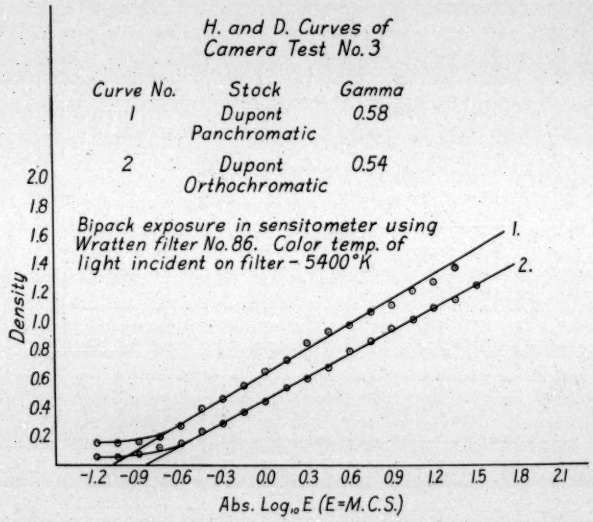
*Tabulation of Data.*

| Camera Test No. | Camera. | Pan Astro Lens. | Wratten Filter. | Neg. | Chart Reflection Factor. | Chart Brightness Apparent M.C. | Film Speed ft./min. | Degrees Shutter. | Lens Stop Number. | Actual $\log_{10} E$. | Calculated $C$. | Calculated $\log_{10} E$ $C = 0.116$. | $\log_{10} E$ Deviation. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Bell & Howell | 2″ | None | Pan | 0.866 | 62400 | 90 | 108° | f 3.2 | 0.75 | 0.095 | 0.85 | − 0.10 |
| 1 | " | " | " | Ortho | " | " | " | " | " | 0.15 | 0.024 | " | − 0.70 |
| 2 | " | " | 86-A | Pan | " | " | " | " | " | 0.84 | 0.117 | " | − 0.01 |
| 2 | " | " | " | Ortho | " | " | " | " | " | 0.32 | 0.035 | " | − 0.53 |
| 3 | " | " | 86 | Pan | " | " | " | " | " | 0.78 | 0.102 | " | − 0.07 |
| 3 | " | " | " | Ortho | " | " | " | " | " | 0.81 | 0.109 | " | − 0.04 |
| 4 | " | " | K-2 | Pan | " | " | " | " | " | 0.88 | 0.128 | " | + 0.03 |
| 4 | " | " | " | Ortho | " | " | " | " | " | 0.63 | 0.072 | " | − 0.22 |
| 5 | Mitchell | 3″ | None | Pan | 0.066 | 4150 | " | 170° | f 5.0 | $\bar{1}$.61 | 0.156 | $\bar{1}$.49 | + 0.12 |
| 5 | " | " | " | Ortho | " | " | " | " | " | $\bar{1}$.55 | 0.136 | " | + 0.06 |
| 6 | " | " | 86-A | Pan | " | " | " | " | " | $\bar{1}$.60 | 0.152 | " | + 0.11 |
| 6 | " | " | " | Ortho | " | " | " | " | " | $\bar{1}$.55 | 0.136 | " | + 0.06 |
| 7 | " | " | 86 | Pan | " | " | " | " | " | $\bar{1}$.61 | 0.156 | " | + 0.12 |
| 7 | " | " | " | Ortho | " | " | " | " | " | $\bar{1}$.59 | 0.149 | " | + 0.10 |
| 8 | " | " | K-2 | Pan | " | " | " | " | " | $\bar{1}$.67 | 0.179 | " | + 0.18 |
| 8 | " | " | " | Ortho | " | " | " | " | " | $\bar{1}$.42 | 0.101 | " | − 0.07 |
| 9 | " | " | None | Pan | " | 3910 | " | " | f 2.3 | 0.18 | 0.130 | 0.14 | + 0.04 |
| 9 | " | " | " | Ortho | " | " | " | " | " | 0.03 | 0.092 | " | − 0.11 |
| 10 | " | " | 86-A | Pan | " | " | " | " | " | 0.24 | 0.149 | " | + 0.10 |
| 10 | " | " | " | Ortho | " | " | " | " | " | 0.15 | 0.121 | " | + 0.01 |
| 11 | " | " | 86 | Pan | " | " | " | " | " | 0.20 | 0.136 | " | + 0.06 |
| 11 | " | " | " | Ortho | " | " | " | " | " | 0.18 | 0.130 | " | + 0.04 |
| 12 | " | " | K-2 | Pan | " | " | " | " | " | 0.08 | 0.103 | " | − 0.06 |
| 12 | " | " | " | Ortho | " | " | " | " | " | $\bar{1}$.95 | 0.077 | " | − 0.19 |

Av. $C = 0.116$.
M.S.E. ($\log_{10} E$) = 0.204.
P.E. = 0.204 × 0.6745 = 0.138.

stituted for $E$ in the exposure formula, and with the data for brightness, exposure time, and lens stop number, the value of the constant $C$ was determined. The value for $C$ having been determined for each individual test on both panchromatic and orthochromatic negatives, the average of the column was taken and found to be 0.116. Using this average value of $C$, log $E$ was computed for each test from the exposure formula. The difference between the computed log $E$ and the actual

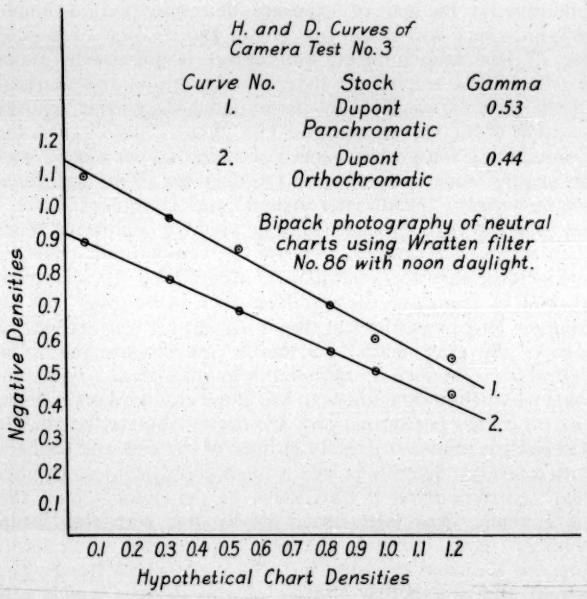
FIG. 1.




log $E$ gives the column of log $E$ deviation which is a measure of the accuracy of the method. By determining the mean square error (M.S.E.) in terms of log $E$, and multiplying by .675, the probable error (P.E.) is obtained. In this case the probable error is 0.138, which means that, by using this photometric method of exposure determination, the probability that the position of the exposure on the log $E$ axis will be within 0.14 log $E$ of the desired position is one-half.

It should be pointed out that, in the cases where a filter was used, log $E$ values are in terms of light incident on the filter and not in terms of transmitted light incident on the film. Since sensitometer exposures were made through the same filter as was used on the corresponding camera test, the consideration of the light incident on the filter makes the intro-

FIG. 2.

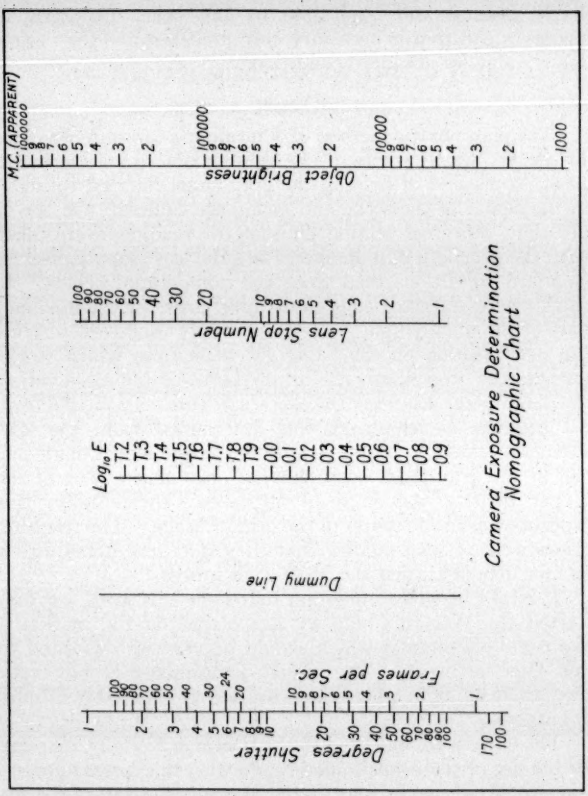



duction of a filter factor unnecessary. This procedure explains why the calculated log $E$ values are the same for equal brightness values regardless of the filter used.

Figures 1 and 2 show a typical set of curves. In Fig. 1 data from a sensitometer exposure using an 86 filter are plotted. The upper H. and D. curve is for the panchromatic

stock, and the lower curve is that of the orthochromatic. The corresponding camera test negative data are plotted in Fig. 2. In this case the negative density is plotted against the gray chart density, which is an H. and D. curve. It will be noticed that the points fall reasonably close to a straight line and, furthermore, that the gammas are approximately equal to the corresponding sensitometer gammas of Fig. 1.

In order to simplify computations when actually using this photometric method of exposure determination, a nomographic chart was made up, giving the relation of desired log $E$, lens stop number, and object brightness in meter candles. The empirically determined value of the constant of the formula was used for determining the correct relative position of the various scales. The "Log $E$ Scale" gives the desired log $E$ for a camera speed of 24 frames per second, and an angular shutter opening of 170 degrees. Two additional scales, namely, "Frames per Second" and "Degrees Shutter," are given so that the chart may be used for conditions other than standard if desired. To use the nomographic chart, it is first necessary to determine the desired log $E$ value from H. and D. curves of the negative stock to be used. As an example let us consider the case of the 50 per cent. reflecting area of the gray chart. Further let us suppose that it is desirable to produce a log $E$ of 0.3 for this area. To determine what lens stop number to use under standard conditions, i.e., 24 frames per second and 170 degree shutter, all that is necessary is to measure the brightness of the area and connect with a straight line the point on the scale of "Object Brightness" corresponding to this value to the point 0.3 on the log $E$ scale. The intersection of this line with the "Stop Number" scale indicates the lens stop number to be used. Suppose a second exposure is to be made at 18 frames per second and an angular shutter of 100 degrees which will produce the same negative density as the test under standard conditions. In this case the auxiliary scales will be needed. Connect 0.3 on the "Log $E$" scale and 170 on the "Degrees Shutter" scale with a straight edge and rotate about the intersection on the dummy line until the straight edge intersects 100 on the "Degrees Shutter" scale and a new log $E$ value is determined. Connect this new log $E$ value and 24 on




the "Frames per Second" scale and rotate about the dummy line as before to 18 and the final log $E$ value results. Connect this final log $E$ value with the brightness value as in the standard case and read the lens stop number from its scale. It might be well to point out that, although this nomographic chart was designed for bipack color negative work on the basis of the 0.116 value for the formula constant, it is per-

fectly general and applicable to any other photographic process. All that is necessary is to predetermine the desired log $E$ value for standard conditions.

SUMMARY.

The photometric method of determining exposure was used in several actual scenes. The routine determination of exposure consisted of holding the gray chart referred to above in the center of the scene and facing the camera. On the 50 per cent. reflecting section photometric readings were taken with the Macbeth illuminometer and the lens stop number for standard conditions read from the nomographic chart. In cases where standard conditions were not used the auxiliary part of the nomographic chart was simply used to determine the new position on the "Log $E$" scale from which to determine the stop number. In all the tests and cases where the photometer was used, the exposures were very satisfactory. All negative development was determined from the sensitometer curves. In printing, the exposure which made one test of the gray chart come out not only neutral but of the proper density was used in all cases. Incidentally, this exposure was in the center of the printer range. The resulting prints were of such quality that they were assembled into a reel for demonstrating the Multicolor process.

It might be well to mention that since this work was first started the Weston Company has placed on the market a photronic photometer which should be very well adapted to this type of work. The visual photometer is not very accurate in sunlight where the eye is accommodated to intense brightness.

The writers are indebted to the Eastman Kodak Company for the use of their sensitometer, and wish to express appreciation to Mr. Emery Huse of the above organization for his helpful suggestions.

# ON THE ATOMIZATION OF LIQUID JETS.

By H. B. HOLROYD, Ph.D.

The atomization of liquids by forcing them through small orifices has attracted the attention of several investigators [1] but up to the present no completely satisfactory results have been obtained. One of the qualitative explanations of the atomization is that it is caused by the turbulent motion of the liquid as it leaves the orifice. Another explanation is that the gas into which the fluid is injected causes the atomization. The first explanation may be given a quantitative form by dimensional reasoning applied in an unusual manner.

This method is to apply dimensional reasoning to obtain an equation for the mean angular velocity of the fluid as it leaves the orifice, and then to apply it again to the process of atomization. The fundamental reason that this method gives a useful equation while the ordinary method of dimensional reasoning does not is that more of the details of the process are used in the analysis, which results in a decrease in the generality of the resulting equation.

We may think of the fluid as being divided into small regions each having an angular velocity, and hence speak of the whole fluid having a mean angular velocity. It is evident that this mean angular velocity of the fluid depends only on the diameter of the orifice, the velocity of flow, and the density and viscosity of the fluid. Dimensional reasoning applied in the usual way gives the result that the mean angular velocity is

$$\omega = \frac{v}{d}\psi\left(\frac{dv\rho}{\mu}\right), \tag{1}$$

in which $\omega$ = mean angular velocity,
$v$ = velocity of flow,
$d$ = diameter of the orifice,
$\mu$ = coefficient of viscosity,
$\rho$ = density of the liquid.

[1] P. H. Schweitzer has given a brief summary of the investigations in Bulletin No. 40 of the Pennsylvania State College.

The equation, of course, is valid only for geometrically similar orifices.

After the liquid leaves the orifice, centrifugal forces tend to break up the jet against the opposing force of surface tension. It appears reasonable to assume that viscosity has a negligible effect during this process, and that the result does not depend on the diameter of the orifice. Dimensional reasoning gives

$$D^3 = k\frac{\lambda}{\rho\omega^2}, \tag{2}$$

in which $D$ = mean diameter of the drops,
$\lambda$ = surface tension,
$k$ = a constant.

From eqs. (1) and (2), the complete equation for the mean drop diameter is

$$D = \left(\frac{\lambda d^2}{\rho v^2}\right)^{1/3} \varphi\left(\frac{dv\rho}{\mu}\right). \tag{3}$$

Equation (2) may be obtained by a method which shows its meaning more completely. Consider a small volume of fluid rotating so that all parts have the same angular velocity. The centrifugal force tending to produce a separation is

$$F = c\rho\omega^2 D^4,$$

in which $c$ is a constant. The force tending to hold the fluid together is

$$F' = c'\lambda D,$$

in which $c'$ is another constant. The fluid can be in equilibrium only if the force of surface tension is greater than the centrifugal force. For the limiting value, $F = F'$,

$$D^3 = \frac{c'}{c}\frac{\lambda}{\rho\omega^2}.$$

It is interesting to obtain an idea of the necessary magnitude of rotation by assuming that the volume of fluid has the form of a sphere, in which case $c = \pi/64$ and $c' = \pi$. With these values

$$D = 4\left(\frac{\lambda}{\rho\omega^2}\right)^{1/3}. \tag{4}$$

There will be instability with a fluid having a density of 0.85 g. cm.$^{-3}$, and a surface tension of 28 g. sec.$^{-2}$ at a peripheral velocity of 240 cm. sec.$^{-1}$ if $D = 0.009$ cm. Of course the drop will not have the form of a sphere; this calculation gives only the order of magnitude. According to the data published by R. Kuehn, a velocity of flow of 4600 cm. sec.$^{-1}$ is required to give a mean diameter of 0.009 cm. Since the peripheral velocity is only 5 per cent. of the velocity of flow, it is reasonable to think that the forces due to turbulent motion are great enough to account for the observed sizes of drops.

The experimental results of R. Kuehn [2] give a partial proof of the validity of eq. (3). Table I is computed from his results. The four atomizers used in his experiments are designated as "without atomizer," "old atomizer," "atomizer II" and "atomizer III." The gas oil had the following properties: density 0.852 g. cm.$^{-3}$, surface tension 28 g. sec.$^{-2}$, viscosity 0.0634 g. cm.$^{-1}$ sec.$^{-1}$. The kerosene had the properties: density 0.812 g. cm.$^{-3}$, surface tension 26.5 g. sec.$^{-2}$, and viscosity 0.0187 g. cm.$^{-1}$ sec.$^{-1}$.

Table I shows that the function of Reynolds number in eq. (3) is a slowly increasing function having the same general behavior as an orifice coefficient. The results with kerosene do not appear to be strictly comparable with those for gas oil. The orifice coefficients, $C_0$, are given in the table for purposes of comparison. The largest Reynolds number for gas oil is only a little smaller than the smallest for kerosene, but the orifice coefficients are quite different, which is not to be expected. It may be concluded from this that the failure of eq. (3) to agree for kerosene and gas oil may be due to differences in the experimental conditions rather than to inaccuracy in the equation.

Dana W. Lee [3] carried out experiments on atomization using apparatus and methods similar to that of Dr. Kuehn. In one set of experiments, geometrically similar orifices were used. According to eq. (3), if the same liquid is used at the same pressure, the mean drop diameter divided by the two-

[2] "Atomization of Liquid Fuels," Der Motorwagen, 1924. A translation is published by the National Advisory Committee for Aeronautics in Technical Memorandums Nos. 329, 330, and 331.

[3] National Advisory Committee for Aeronautics Report No. 425.

thirds power of the diameter of the orifice is a constant if the function of Reynolds number is considered to be constant. Due to the difficulty in making orifices which are truly geometrically similar, exact agreement in this type of experiments cannot be expected.

TABLE I.

| Atomization Pressure Kg./cm.². | Gas Oil. | | | | | | | | | Kerosene. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Old Atomizer. | | | Without Atom. | | Atom. II. | | Atom. III. | | Old Atomizer. | | |
| | $\frac{dv}{\mu}$ | $\frac{dv}{\mu}\cdot\left(\frac{dv\rho}{\mu}\right)^{\frac{1}{3}}$ | $C_v$ | $\frac{dv}{\mu}$ | $\frac{dv}{\mu}\cdot\left(\frac{dv\rho}{\mu}\right)^{\frac{1}{3}}$ | $\frac{dv}{\mu}$ | $\frac{dv}{\mu}\cdot\left(\frac{dv\rho}{\mu}\right)^{\frac{1}{3}}$ | $\frac{dv}{\mu}$ | $\frac{dv}{\mu}\cdot\left(\frac{dv\rho}{\mu}\right)^{\frac{1}{3}}$ | $\frac{dv}{\mu}$ | $\frac{dv}{\mu}\cdot\left(\frac{dv\rho}{\mu}\right)^{\frac{1}{3}}$ | $C_v$ |
| 8 | 1710 | 5.04 | 0.56 | 1800 | 5.20 | 1450 | 4.50 | 1360 | 4.35 | 6260 | 3.72 | 0.60 |
| 12 | 2380 | 5.37 | 0.63 | 2510 | 5.54 | 1840 | 4.47 | 1750 | 4.40 | 8540 | 4.12 | 0.68 |
| 16 | 2840 | 5.48 | 0.67 | 3030 | 5.70 | 2160 | 4.52 | 2030 | 4.40 | 10200 | 4.27 | 0.71 |
| 20 | 3290 | 5.55 | 0.68 | 3490 | 5.84 | 2450 | 4.61 | 2320 | 4.49 | 11690 | 4.38 | 0.72 |
| 24 | 3680 | 5.71 | 0.69 | 3870 | 5.92 | 2680 | 4.62 | 2550 | 4.47 | 12810 | 4.46 | 0.73 |
| 28 | 4000 | 5.84 | 0.70 | 4260 | 6.08 | 2970 | 4.77 | 2780 | 4.56 | 14100 | 4.61 | 0.74 |
| 32 | 4360 | 5.87 | 0.71 | 4610 | 6.18 | 3200 | 4.77 | 3000 | 4.65 | 15100 | 4.66 | 0.75 |
| 36 | 4650 | 5.95 | 0.72 | 4940 | 6.23 | 3420 | 4.87 | 3230 | 4.68 | 16280 | 4.74 | 0.75 |
| 40 | 4970 | 6.08 | 0.72 | 5230 | 6.30 | 3650 | 4.95 | 3420 | 4.75 | 17100 | 4.74 | 0.75 |
| 44 | 5230 | 6.13 | 0.73 | 5550 | 6.38 | 3870 | 5.02 | 3620 | 4.79 | 18000 | 4.83 | 0.76 |
| 48 | 5520 | 6.18 | 0.73 | 5840 | 6.44 | 4060 | 5.04 | 3810 | 4.80 | 19100 | 4.90 | 0.76 |

TABLE II.

| Orifice Diam. inches. | Volumetric Mean Drop. Diam. ins. | $D/d^{2/3}$. |
|---|---|---|
| 0.008 | 0.00069 | 0.0173 |
| 0.020 | 0.00133 | 0.0180 |
| 0.030 | 0.00161 | 0.0169 |

Table II is computed from Lee's results. The agreement is fairly good. One difficulty is in the definition of a mean. An exact definition cannot be given in eq. (3) because of the manner of derivation. Several mean drop diameters can be defined. If the others used by Lee are used to check the equation, the agreement is not as good as the above.

If we neglect the function of Reynolds number in eq. (3), considering it to be a constant, then the product of the mean drop diameter and the cube root of the injection pressure should be a constant for a given liquid and orifice. Table III is computed from Lee's data. The agreement here is as good as one can expect considering the inaccuracy in neglecting the

TABLE III.

| Injection Pressure lbs./sq. in. | Volumetric Mean Drop. Diam. ins. | $DP^{1/3}$. |
|---|---|---|
| 880 | 0.00170 | .0163 |
| 2280 | 0.00158 | .0208 |
| 4160 | 0.00128 | .0206 |
| 5700 | 0.00127 | .0226 |

$P$ = injection pressure.

function of Reynolds number and the possible experimental errors in the data.

We may conclude that the available experimental data show that the explanation of turbulence is probably correct for the rates of flow used in the experiments and that eq. (3) is probably correct. Further experimental results should be obtained before it can be finally accepted.

The problem of atomization has been studied mostly in connection with engines, and it is perhaps for this reason that the experimenters used oil. The experimental methods are so laborious that comparatively few data have been obtained. There are too many drops to be counted, so there may be a considerable error in sampling.

It appears that a better experimental method is to use liquids which will solidify before coming into contact with any solid surface. The drops may be kept and studied at leisure. The author tried spraying melted beeswax using an atomizer in which the atomization depends on an air jet. The wax solidifies fairly quickly but not until it is atomized. The particles float like dust in the air.

There appears to be some advantage in using alloys of low melting point. With such dense substances, the drop sizes and size distribution can be determined by sedimentation methods. This method may make it possible to obtain results of high precision.

**The Rapid Development of Patina on Copper** (*Brass World*, Vol. 28, p. 183, 1932).—Some one with time on their hands and a fair degree of inquisitiveness might like to trace the origin of the idea that the natural green patina on copper consists of copper basic carbonate. Everyone is acquainted with the green coating that gradually forms upon copper roofing and sheathing during prolonged exposure to the weather. Acting on the assumption that patina was copper basic carbonate many have tried, unsuccessfully, to produce it by artificial means.

J. H. Freeman, Jr., and P. H. Kirby decided to analyse the patinas on samples of copper roofing secured in widely separated localities and much to their surprise found all of the specimens to consist of the basic sulfate rather than the basic carbonate. Armed with this basic information the investigators were able to develop a successful method of forming patinas artificially. It is done by spraying a ten per cent. solution of ammonium sulfate upon the clean copper surface for a period of about twenty-four hours. This treatment produces a dark blue-green adherent patina that compares favorably with nature's product requiring 12 to 14 years to form.

C.

## NOTES FROM THE U. S. BUREAU OF STANDARDS.*

### AIRCRAFT SPEED INSTRUMENTS.

A comparison of the report on "Aircraft Speed Instruments," just published by the National Advisory Committee for Aeronautics as Technical Report No. 420, with an earlier paper on the same subject, "Aircraft Speed Instruments," Technical Report No. 127, 1922, shows from a new angle the rapid strides which aviation has made in the past decade. Practically all of the air-speed meters described in the earlier paper as in ordinary service are now obsolete. The pitot-static tube type has become the standard. Indicators have been standardized and their accuracy greatly increased. Their range of indication has also been much extended, not only for the higher speeds of present day airplanes but also for lower speeds. Metallic cases have been entirely displaced by cheaper, lighter, non-corrosive cases of bakelite or similar materials.

Naturally, the report devotes special attention to the pitot-static tube meter. The venturi forms, so important in 1922, are only briefly discussed as they are now used very rarely. Other sections of the report cover anemometers of the Robinson cup and vane types, pressure plate instruments, and hot wire anemometers.

An interesting instrument of the vane anemometer type is the suspended head air-speed meter developed at the Bureau of Standards for use on airships such as the *Los Angeles* and *Akron*. The instrument consists of a two-bladed fan at the nose of a stream-lined case which is suspended by cable about 40 feet below the control car where it is unaffected by disturbances of the air due to the movement of the airship. The fan is set into rotation by the motion of the case through the air and the speed of rotation of the fan is transmitted electrically by apparatus in the case to the dial of an instrument in the control car, which is graduated to give indications of air speed.

* Communicated by the Director.

The report also contains a discussion on methods of ground speed measurement, with references to the more important modern instruments.

A bibliography on air-speed measurement is included for those who wish to go into the subject in more detail.

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### THE OERSTED.

At its plenary meeting in Oslo in July, 1930, the International Electrotechnical Commission adopted the name "oersted" for the unit of magnetizing force (magnetic intensity). As the commission has no legal authority, the application of its recommendations in practice depends upon the attitude of technical organizations in the various countries concerned. In the United States, the name "oersted" was previously used for the unit of magnetic reluctance, and this fact made the acceptance of the new proposal somewhat doubtful. The new use of the name has, however, been accepted by authoritative technical bodies.

The American Society for Testing Materials through its committee on magnetic properties has adopted the name and included it in its latest revision of specifications for methods of test for magnetic properties of iron and steel, and also in its tentative definitions of terms, with units and symbols, relating to magnetic testing.

The sectional committee on electrical definitions of the American Standards Association under the sponsorship of the American Institute of Electrical Engineers in its report of August, 1932 (C42–1932), accepts the name "oersted" for the c.g.s. electromagnetic unit of magnetic intensity. A further indication of the general acceptance of the term is its use by the authors of several recent articles on magnetic subjects.

In accordance with the general principle of following accepted practice as indicated by the decisions of authoritative technical bodies, the bureau has adopted for its own use the name "oersted" for the unit of magnetizing force or magnetic intensity. The term "gilbert per cm." previously used still has the same significance and may be used interchangeably with "oersted" if preferred.

## RED LEAD PAINT.

In recent years a very fine grade of red lead has appeared on the market. Its true red lead content will vary from 95 to over 99 per cent. $Pb_3O_4$. Its texture is soft, very fine, and its color is lighter (a bright red-orange) than the average red lead. Its apparent bulk is much greater than the ordinary red lead. Where the ordinary red lead requires about 32 pounds to the gallon of linseed oil to make a paint of good brushing properties, the fine grade of red lead requires only 16 pounds to the gallon of oil. The finish of the paint coat is more glossy with the fine red lead. It has been observed at the bureau that using 95 per cent. grade red lead and 85 per cent. grade red lead in the same thinning formula, the 95 per cent. grade gives more gloss to the paint coat. The first or "shop coat" paint on metal should dry to a dull finish so that the "field coats" may adhere properly. One mistake commonly made is to apply a priming coat paint made from red lead and linseed oil. The paint dries to a slick, glossy finish, and trouble is encountered in trying to apply another paint over this surface. The red lead paint should contain turpentine (or mineral spirits) and drier. Apparently with the increasing use of the fine grade of red lead this trouble from glossy undercoats is increasing. Less oil and much more volatile thinner than is now used will probably be the answer.

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## ROOF EXPOSURES OF RED LEAD PAINTS.

Nearly 4 years ago (January, 1929), a number of red lead paints (all experimental) were exposed on the roof of the chemistry building of the bureau. These paints varied from 20 up to 100 lbs. of red lead to the gallon of linseed oil. All paints were applied in two coats on sandblasted steel panels. At this date, the two lightest weight paints have failed by rusting. These are 20 pounds and 22 pounds of red lead to the gallon of oil. Paint containing 25 pounds of red lead to the gallon of oil is now showing definite (but not bad) rusting. All of the other paints appear to be in sound condition. Under the microscope the appearance of the panels shows that red lead paints fail (exclusive of appearance)

by chalking and cracking—possibly first checking. Microscopic examination of the paint coat will show rather bad checking a long time before rust begins to appear. Even when these checks develop into cracks apparently extending down to the sandblasted steel, rusting does not appear for some time.

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### PLASTICITY OF GROUND COAT ENAMELS.

It has several times been pointed out in publications on enamel that the elastic properties of an enamel, along with its tensile strength and coefficient of expansion, are indicative of its resistance to mechanical failure. A considerable amount of experimental work has been reported in the literature regarding the coefficient of expansion of enamels, including an article in Technical News Bulletin No. 184 (August, 1932).

The same group of ground coat enamels mentioned in the above item have been tested for modulus of elasticity, the specimens being rods of enamel about 0.3 to 0.5 mm. in diameter and 60 mm. in length. Sodium oxide and boric oxide were substituted one for another between the limits 11–17 per cent. and 13–19 per cent., respectively, and flint and feldspar were substituted one for another within the limits 25–35 per cent. These variations in composition produced no marked effect upon the modulus of elasticity of the enamel. The lowest mean value was about 8,150 kg./mm.$^2$, and the highest about 8,320 kg./mm.$^2$, an increase of scarcely more than 2 per cent.

The conclusion was that within the limits of composition studied, which are rather typical of commercial practice, variations in modulus of elasticity may be overlooked as an important factor affecting the resistance of the enamels to mechanical failure.

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### MELTING POINT OF LEAD OXIDE.

A study of phase equilibria in the system $PbO$-$K_2O$-$SiO_2$ has been started recently, and the results should prove of value to producers of glazed ceramic ware and of glass containing lead. Practically all of the glazes, on ceramic whiteware and pottery, as well as vitreous enamels contain $K_2O$

introduced as feldspar, many contain lead, and all contain silica. A number of investigations of the system $PbO$-$SiO_2$ are recorded, but the resultant diagrams are so conflicting as to justify further study.

The first step in this study was the determination of the melting point of PbO. The material used is a sublimed litharge containing no detectable quantities of zinc, nickel or manganese; less than 0.001 per cent. iron; 0.002 per cent. copper; and 0.018 per cent. bismuth. The melting point, determined by means of heating curves and a bare Pt. to Pt. Rd. couple inserted in the melt, was 886 ± 2° C. This compares favorably with the value of 886° determined in 1931 by Krakau and Vachrameev. Many other values are given in the literature, varying from 830° (1897) to 906° (1907), but most of the values lie between 875° and 890° C.

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### HIGH TENSION INSULATOR PORCELAINS.

Glazed and unglazed rods of high-tension insulator porcelains, which had been heated in commercial kilns to the regular maturing temperatures (averaging approximately cone 10 or 1,250° C.) for from one to seven times, were submitted by three manufacturers. These rods were tested for resistance to failure in bending and in compression. They were tested also to determine modulus of elasticity, strain between glaze and body, and linear thermal expansion. Specimens from one manufacturer were examined petrographically.

Moduli of rupture of the glazed rods subjected to the maximum number of reheatings had decreased from 15 to 70 per cent., and the maximum decrease in resistance to crushing was 50 per cent.; equivalent values for unglazed rods showed decreases of from five to 25 per cent., and 35 per cent., respectively.

Decrease in strength of unglazed rods is attributed to an altered and probably "overfired" condition of the body, while the greater decrease in strength of glazed rods as compared with unglazed is attributed to a combination of the altered body and stresses produced by the glaze.

The final report is scheduled to appear in the January, 1933, *Bulletin of the American Ceramic Society.*

### BASE EXCHANGE CAPACITIES OF CLAYS.

In studying a number of English china clays it was found that their exchangeable base capacity seemed to be a distinguishing property. As a consequence, the work was extended to other clays and at the present time the total exchangeable base capacities of 25 different clays have been determined. The clays now studied are divided into four groups and their maximum, minimum, and average base exchange capacities are given below in milliequivalents per 100 grams of clay.

| | Maximum. | Minimum. | Average. |
|---|---|---|---|
| 13 English china clays | 7.2 | 2.5 | 4.9 |
| 6 American kaolins, excluding Florida kaolins | 7.4 | 4.1 | 5.7 |
| 3 Florida kaolins | 15.7 | 7.8 | 12.6 |
| 3 ball clays | 15.7 | 5.8 | 11.8 |

It will be noted that the American kaolins, with the exception of those from Florida, differ only slightly in this property from the English china clays, the former having higher exchange capacities. The Florida kaolins have base exchange capacities conforming to those of the ball clays. The latter include one Tennessee clay, which gave the lowest value, one Kentucky clay, and one English clay, which showed the highest exchange capacity.

# THE FRANKLIN INSTITUTE.

## STATED MONTHLY MEETING, DECEMBER 21, 1932.

The regular monthly meeting of the Institute was called to order at eight-fifteen by the President, Mr. Nathan Hayward.

The Secretary announced that the minutes of the November meeting had been published in full in the JOURNAL for December and stated that unless objections were offered the minutes would be approved as printed. As no objection was offered, the President ruled the minutes approved.

The Secretary then stated that at this meeting nominations were in order for the officers of the Institute and for one-third of the members of the Board of Managers who would be elected at the monthly meeting in January and presented the following nominations:

| *Office* | *Nominee* | *Nominated by* |
|---|---|---|
| *President* | Nathan Hayward | Henry Howson<br>Marshall Morgan<br>W. Chattin Wetherill |
| *Vice-Presidents* | Henry Howson<br>C. C. Tutwiler<br>Walton Forstall<br>W. Chattin Wetherill | Charles E. Bonine<br>G. H. Clamer<br>Paul J. Sartain |
| *Treasurer* | Benjamin Franklin | James Barnes<br>H. Ennis Jones |
| *Board of Managers:* | | |
| To serve three years: | Edward G. Budd<br>Dr. Walton Clark<br>Clarence A. Hall<br>Dr. George A. Hoadley<br>A. Atwater Kent<br>Hon. George Wharton Pepper<br>James S. Rogers<br>Haseltine Smith | Walton Forstall<br>James Stokley<br>Arthur W. Goodspeed |

The President thereupon called for other nominations from the floor, but no such nominations were offered. Upon motion the nominations were declared closed.

There was no other business so that at eight-twenty-five the President presented as the speaker of the evening Dr. D. B. Steinman, consulting engineer, New York City, who spoke very delightfully on the subject "The Design and Construction of the St. Johns Bridge at Portland, Oregon." The speaker emphasized particularly the efforts which had been made to make the bridge æsthetically

satisfactory. He also, of course, dealt fully on the engineering features involved in the design and construction.

The reading of the paper was followed by an animated and enthusiastic discussion.

The meeting was closed with an expression of thanks by the President to Dr. Steinman.

HOWARD MCCLENAHAN,
*Secretary.*

## COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, December 14, 1932.*)

HALL OF THE COMMITTEE,
PHILADELPHIA, DECEMBER 14, 1932.

MR. EDWARD L. CLARK *in the Chair.*

The following report was presented for final action:

No. 2928: Stream Line Filter.

This report recommended the award of the Certificate of Merit to Doctor H. S. Hele-Shaw, of London, England, "In consideration of his development of a superior filtering device involving stream line principles."

The following reports were presented for first reading:

No. 2921: McAdam's Work on Corrosion Fatigue.
No. 2956: Integrating Flume Meter.
No. 2957: Color Photography.
No. 2962 } Franklin Medal.
No. 2963 }

GEO. A. HOADLEY,
*Secretary.*

## MEMBERSHIP NOTES.

### ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, December 21, 1932.*)

RESIDENT.

MR. WILLIAM H. DUBARRY, Administrative Officer, University of Pennsylvania, Philadelphia, Pa. For mailing: The Belgravia, 1811 Chestnut Street, Philadelphia, Pa.

NON-RESIDENT.

DR. ARTHUR FLEISCHER, Chemist, 1511 Fox Building, Philadelphia, Pa. For mailing: 52 Magnolia Street, Hartford, Connecticut.

STUDENT.

MR. FREDERICK SCHMID, JR., Student, 265 South Eleventh Street, Philadelphia, Pa.

### CHANGES OF ADDRESS.

MR. EDGAR W. BAIRD, 10 West Chestnut Avenue, Chestnut Hill, Phila., Pa.
MR. CLARENCE R. CLAGHORN, 124 South Calvert Street, Baltimore, Maryland.

MR. F. L. DUBOSQUE, 4376 North Bay Road, Miami Beach, Florida.
MR. FREDERICK S. FELDHEIM, 501 South Forty-sixth Street, Philadelphia, Pa.
MR. FRANCIS B. FOLEY, 247 West Tulpehocken Street, Germantown, Phila., Pa.
MR. JAMES B. FRANCIS, 8103 Eastern Avenue, Wyndmoor, Pa.
MR. PERCY S. LYON, Commercial Engineering Div., Air Conditioning Dept., General Electric Company, 120 Broadway, New York City.
MR. OTTO T. MALLERY, 1427 Spruce Street, Philadelphia, Pa.
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## BOOK REVIEWS.

WÖRTERBUCH DER CHEMIE, von Willy H. Thurow. Zweiter Teil, Deutsch-Englisch. 287 pages, 11.5 × 18 cms. Berlin—Schöneberg. Verlag Dr. Arthur Tetzlaff, 1932.

About two years ago we had the pleasure of acknowledging and reviewing Part One of the author's Dictionary of Chemistry which represented the English-German portion. As might be expected the Second Part (German-English) would have considerably greater utility in an English-speaking country and it is with heightened interest we welcome the opportunity to look over this sequel volume.

Those of us not fortunate enough to have more than a smattering knowledge of the German language will have many occasions to use this dictionary. It is difficult to determine how complete a book of this type may be merely by a casual examination. Full appreciation can come only through its use as an aid to making translations. A superficial examination indicates that the author has done his work with commendable thoroughness and that this dictionary compares very favorably with any of those of comparable size printed in this country.

T. K. CLEVELAND.

VIBRATION PREVENTION IN ENGINEERING. By Arthur L. Kimball, Research Laboratory, General Electric Company. viii–145 pages, illustrations, 15 x 23 cms., cloth. New York, John Wiley & Sons, Inc., 1932. Price $2.50.

Balancing the moving parts of a mechanism to prevent vibration or to reduce it to a tolerable amount is a problem which arises in the design of every high-speed mechanism. Unfortunately the additional members required to even approximately counteract unbalance introduces complication which is frequently impracticable, and designers have generally been content to apply preventive measures to the mechanism as a whole. Including the balancing of actual rotating parts, vibration prevention embraces those principles of pure mechanics which may be applied to equilibrating either individually or collectively equivalent and opposite impulses, applied at suitable points, to those which produce the disturbance. Another method of procedure is to utilize elastic supports so proportioned that the time of vibration of the mass of the mechanism as a whole may be in proper relation to the periods of the impulses of the moving parts to diminish the rate and magnitude of impulses which reach the foundation. In order not to err in the application of such simply specified measures, a strict examination into the dynamic principles involved is highly essential.

The author accordingly has provided a systematic and deductive account of the dynamical principles which are employed in dealing with vibration phenomena. The application to certain typical problems on vibration-producing conditions, and the principles of balancing machines which are employed in determining the magnitude and position of weights to correct unbalance are discussed at ample length. The important field of the prevention of noise and vibration by elastic supports, and the theory of vehicle suspension are examined theoretically with an illustration of an application to a motor-drive installation. Other related topics, such as critical speeds of rotors, turbine wheel vibrations, theory of damping, shaft

whirling, and vibration damping in turbine buckets add interest and value to the discussion. The mathematics employed are of undergraduate college grade, and while used unsparingly are of simple character. The book is one of a series written in the interest of the Advanced Course in Engineering of the General Electric Company, and is based upon the substance of a series of lectures presented at the Harvard Engineering School during the season of 1930–1931.

The methods of correcting unbalance and vibration which are developed are in general obvious enough, but the question of "how much and where?" is more difficult to answer. The author appears to have found the shortest path to the means of finding the answer.

L. E. P.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 442. A Comparison between the Theoretical and Measured Longitudinal Stability Characteristics of an Airplane, by Hartley A. Soule and John B. Sheatley. 16 pages, illustrations, 23 × 29 cma. Washington, Superintendent of Documents, 1932. Price five cents.

This paper covers an investigation of the application of the theory of dynamic longitudinal stability, based on the assumption of small oscillations, to oscillations an airplane is likely to undergo in flight. The investigation was conducted with a small parasol monoplane for the fixed-stick condition. The period and damping of longitudinal oscillations were determined by direct measurements of oscillations in flight and also by calculation in which the factors that enter into the theoretical stability equation were determined in flight. A comparison of the above-mentioned characteristics obtained by these two methods indicates that the theory is applicable to the conditions encountered in flight.

The investigation was extended to determine the feasibility of calculating the stability characteristics from basic data of the type that would be available to a practicing designer. The results of this phase of the work show that for the power-off condition the agreement between the actual and predicted stability characteristics was reasonably satisfactory, except perhaps when the predicted stability is close to neutral. For the power-on condition the stability can not be predicted owing to the present lack of information concerning slipstream effects. Further progress in a solution of the problem of longitudinal stability depends largely on increasing the knowledge of these effects.

Report No. 443. Pressure-Distribution Measurements on the Hull and Fins of a 1/40-Scale Model of the U. S. Airship "Akron," by Hugh B. Freeman. 15 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932. Price five cents.

This report presents the results of measurements of pressure distribution conducted in the propeller-research wind tunnel of the National Advisory Committee for Aeronautics on a 1/40-scale model of the U. S. airship "Akron" ("ZRS–4"). The pressures, which were measured simultaneously at nearly 400 orifices located at 26 stations along one side of the hull, were recorded by two photographic multiple manometers placed inside the model. The hull pressures were measured both with and without the tail surfaces and the control car for eight angles of pitch varying from 0° to 20° and at air speeds of approximately 70 and 100 miles per hour. The pressures were also measured at approximately 160 orifices on one horizontal fin for the above speeds and pitch angles and for nine elevator angles.

The integrated transverse forces and the integrated moments about the center of buoyancy were in good agreement with the forces and moments measured on the balances in the force tests. The pressural drag of the hull was found to be practically zero within the accuracy of the tests. The pressure forces on the after portion of the hull in the presence of the tail surfaces were found to contribute more than 40 per cent of the total fin moments measured in the force tests. Negative pressures as great as seven times the dynamic pressure of the undisturbed air stream were measured on the leading edge of the horizontal fin at the 20° pitch angle with 20° down elevator.

Report No. 445. Working Charts for the Determination of the Lift Distribution Between Biplane Wings, by Paul Kuhn. 17 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1932. Price ten cents.

In this report are presented empirical working charts from which the distribution of lift between wings; viz, the fraction of the total lift borne by each, can be determined in the positive lift range for any ordinary biplane cellule whose individual wings have the same profile. The variables taken directly into account include airfoil section, stagger, gap/chord ratio, decalage, chord ratio, and overhang. It is shown that the influence of unequal sweepback and unequal dihedral in upper and lower wings may be properly provided for by utilizing the concepts of average stagger and average gap/chord ratio, respectively. The effect of other variables is discussed, but they have not been included in the charts either because their influence was obviously small or because insufficient data existed to make possible a complete determination of their influence. All available pertinent biplane data were analyzed in establishing the charts, and in some cases theoretical relationships were utilized to establish qualitative tendencies.

THE FREE ENERGIES OF SOME ORGANIC COMPOUNDS, by George Sutton Parks, Associate Professor of Chemistry, Stanford University, and Hugh Martin Huffman, Assistant Professor of Biochemistry, California Institute of Technology. American Chemical Society, Monograph Series, 251 pages, tables, diagrams, 15 × 23.5 cms. New York, The Chemical Catalog Company, Inc., 1932. Price $4.50.

"The Free Energies of Some Organic Compounds" is a recent member of the American Chemical Society Monograph Series and represents another forward step in the gathering together and intelligent summarizing of useful knowledge to chemists.

This book serves a two-fold purpose. To the chemist concerned with the practical aspects of the metamorphoses of organic compounds it is valuable for having collected and classified much pertinent free energy data. Obviously, this information will find particular application to the petroleum industry where the "cracking" (subjection to heat and pressure) of hydrocarbons is almost universally employed and involves a great complexity of organic reactions. Free energy data also find practical application in the well-known synthetic process for making methyl alcohol from water-gas. Theoretical and research chemists will readily appreciate this book. Probably the most worthy of the authors' contributions has been that of determining the relative "weighting" or reliability

of the respective datum. In addition, they have tried to point out the gaps that exist in the free energy data for various homologous series as well as the numerous fertile fields for research yet remaining.

The subject matter is arranged in accordance with that of other books on organic compounds. The paraffin hydrocarbons lead off followed by the unsaturated aliphatics then the cyclics. Prior to dealing with the compounds in their order, the authors start with a welcome preliminary chapter on Some Fundamental Thermodynamic Considerations followed by a section dealing with Notation, Fundamental Constants and Some Generally Useful Data. In the first chapter, four acknowledged methods of determining free energy changes are discussed in some detail. A practical example of each method's "modus operandi" is included. Following the hydrocarbons, consideration is paid to the oxygenated organic compounds such as alcohols, phenols, carboxylic acids, aldehydes, ketones, ethers, acetals, esters, anhydrides and sugars. Among the nitrogen compounds urea holds a position of importance due to its possible industrial uses. The halogenated hydrocarbons command considerable attention as do also the sulfides and mercaptons. There is a timely chapter on the Effect of Modifications in Molecular Structure upon the Molal Entropy and Free Energy. Equally instructive is a chapter containing a table of the free energies of over one hundred and fifty organic compounds and examples illustrating the use of such data. The appendix contains a note on the concept of entropy and the description of a method for extrapolating specific heat curves of organic compounds below the temperatures of liquid air.

T. K. CLEVELAND.

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*The Early Years of Modern Civil Engineering*, by Richard Shelton Kirby and Philip Gustave Laurson, 324 pages, illustrations, maps, 16 × 24 cms. New Haven, Yale University Press, 1932. Price $4.00.

*L'Univers Électromagnétique par une Nouvelle Loi de la Gravitation*, par Max Franck, 123 pages, 14 × 22.5 cms. Paris, Gauthier-Villars et Cie, 1932. Price 15 francs.

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## CURRENT TOPICS.

**Iodine as a Bactericide.**—Some very interesting research upon the disinfecting power of iodine solutions recently has been published in the *Journal of the American Pharmaceutical Association.* The first of three papers was prepared by G. M. Karns and describes the wetting power of iodine from various antiseptic solutions. It should be borne in mind that iodine is quite soluble in alcohol, acetone and similar liquids while it is dissolved by water to only a slight extent. These facts no doubt explain why practically all disinfecting iodine solutions have alcohol as the solvent. However, iodine has another property, the utilization of which promises to make available a much improved type of iodine disinfectant. This remarkable characteristic of iodine is its greatly increased solubility in water solutions of readily soluble iodides. Thus, in pure water, not sufficient iodine will dissolve to give a solution of adequate bactericidal power, while if an aqueous solution of sodium or potassium iodides is used more than sufficient iodine can be dissolved to give an antiseptic solution of practical strength.

Karns has logically assumed that the antiseptic value of an iodine solution must be a function of the ability of the solution to deposit iodine on or allow it to be absorbed by the flesh surface to be disinfected or protected from infection. This facility of giving up its iodine has been termed as the wetting power of the solution and the investigator has found that the wetting power of iodine from aqueous iodide solutions is notably superior to that from alcohol and glycerin solutions.

The antiseptic value of aqueous iodine-iodide solutions having been established, Karns, Cretcher and Beal now set to work to develop a solution of a concentration and constituent-ratio that should be ideal from the physiological as well as the antiseptic standpoint. The adopted, theoretically balanced solution, was prepared from a mixture of 100 parts iodine, 4.4 parts calcium iodide hexahydrate, 4.8 parts potassium iodide and 110.4 parts sodium iodide. Clinical trials of solutions of the above type over a period of a year have shown that for hospital use, for the preparation of operating fields and for direct application to open wounds, a solution of 2 per cent. free iodine has been found most satisfactory. For use in home medicine cabinets and for use in the mouth, 3 per cent. strength is to be preferred. Contrary to the usual method of

application, such a solution is applied in excess and allow to remain in place from 15 to 30 seconds. The excess may then be removed with absorbent cotton or by washing with water and the iodine dose will remain behind. Experience to date would tend to show that this solution is considerably less painful to open wounds than the well-known tincture or alcoholic preparation. What is more, there have been no instances reported where this aqueous solution has produced blisters or burns on the skin.

The third step in establishing the value of this improved iodine antiseptic was to measure its phenol coefficient, that is, compare its bactericidal power with that of phenol (carbolic acid) at similar concentrations. This piece of research has been carried out by L. Gershenfeld and R. E. Miller and published in the *J. of the Am. Pharm. Assn.* for September 1932. They found that 3 per cent. solutions of iodine were superior to any of the other commonly used bactericidal agents in the dilutions most frequently employed.

C.

**Controling Explosions** (*Chemistry and Industry*, Vol. 51, p. 957). —Professor William A. Bone, the well known English investigator of gaseous combustions, recently regaled the members of the Royal Society with his adventures in the realm of "Gaseous Combustion at High Pressures." He referred particularly to explosions of gas mixtures of carbon monoxide, oxygen and nitrogen. Nitrogen gas is relatively inert chemically and its passive resistance to combining with other elements has been no end of bother to those engaged in the production of synthetic nitrogen. Therefore, a very interesting result from such explosions as Prof. Bone perpetrated was the formation of nitrogen oxide in concentrations that would interest the makers of synthetic nitrogen.

If a 10 per cent. nitrogen oxide formation could be obtained in such explosions they would warrant commercial development. For this reason Prof. Bone set out to conduct explosions at still greater pressures. He planned to explode hydrogen-air and carbon monoxide-air mixtures at initial pressures of 250 to 1000 atmospheres (about 6.5 tons per sq. in). The explosion pressure could be expected to reach 10,000 atmospheres or 65 tons per sq. in. These explosions were made in a chamber 3 in. long and 1½ in. diameter cut in a forging of nickel-chromium—molybdenum steel. In addition, this billet was wound with 95 layers of steel wire as in naval-gun construction. At an intial pressure of 500 atmospheres, the hydrogen-air explosion was quite normal and lasted about 0.02 seconds. At 750 atmospheres a violent instantaneous "detonation" occurred that did considerable damage to the screw threads of the

apparatus and it was not deemed advisable to try still higher pressures. A carbon monoxide-air mixture however, was exploded at 1000 atmospheres and the pressure increased to 7100 atmospheres.

In order to better investigate the nitrogen oxide formation in exploding mixtures of carbon monoxide oxygen and nitrogen, a very clever piece of apparatus was devised. An explosion cylinder was fitted at one end with a steel disc, the strength of which could be regulated so that it burst at some predetermined moment during the explosion suddenly liberating the gaseous explosion products into a large "expansion chamber" from which samples could subsequently be withdrawn. In a particular series of experiments the disc gave way at the point of maximum pressure in one instance and 0.06 seconds later in another. In that short period the concentration of nitrogen oxide had increased from 3.3 to 5.4 per cent. To date the maximum nitrogen-oxide yield has been about 6 per cent. at initial pressures of 88 atmospheres.

One of Professor Bone's demonstrations consisted in burning carbon monoxide in an atmosphere of air compressed to about 700 lbs. per sq. in. The combustion products contained about 2 per cent. nitrogen tetroxide ($NO_2$).

C.

**Calculus Helps Cut Waste in Cutting of Soles.**—The Institute has received a very interesting paper written by A. T. McKAY, the head of the mathematics and statistics department of The British Boot, Shoe, and Allied Trades Research Association. The problem presented to the author was that of finding the most economical method of cutting up leather according to patterns of different shapes and size. Take, for example, shoe soles. There may be well up to one hundred sizes and styles. These soles are stamped out by a knife. These knives are expensive to make, require considerable care and their frequent interchanging represents an inconvenience. The shoe trade has found it possible to cut out the several hundred shapes required using three knives at the most. Now the problem is to determine what size each of the knives should have so that the shapes may be cut with a minimum of wastage.

This method of determining the size of a master stamping-knife will find application in other trades such as the celluloid and rubber industries and the pattern making trade. First, each pattern is given a number representing the frequency of demand or sales value. The areas are determined by means of a planimeter or by weighing and calculating the area knowing the unit area weight of the pattern material. The mean area of the patterns is found by multiplying the area of each pattern by its frequency number,

adding the products and obtaining the mean by dividing this sum by the sum of the frequency numbers. Another value, the standard deviation, must be determined. This is done by taking the difference between the mean area and that of each shape, squaring the result, summing all such terms dividing by the total number of shapes and taking the square root of the resulting quantity. Now suppose it is decided to use two knives for the cutting of a series of shapes. Of course the larger knife will be the size of the largest shape. Deduct the mean area from that of the largest shape and divide the result by the standard deviation. By referring this value to a table a corresponding figure is obtained which is multiplied by the standard deviation and added to the mean area. The result is the area of the smaller-size knife. A similar procedure, but a different table, is used for determining the respective areas for a set of three knives. The real work in this problem was the preparation of the tables. The values found therein were worked out with the aid of calculus. The various integrating operations cannot be included here but may be obtained from the original manuscript.

C.

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